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A computer program for investigating atmospheric effects on laser designators.

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THESIS

A COMPUTER PROGRAM FOR INVESTIGATING
ATMOSPHERIC EFFECTS ON LASER DESIGNATORS

by

Scott R. Crager

March 1982

Thesis Advisor: E.A. Milne

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This thesis presents a computer program designed to analyze the data from a TV camera for investigating laser beam propagation through the atmosphere. It uses aspects of Fourier optical theory to analyze the TV image to measure the effects of atmospheric disturbance and platform stability on the target spot. The understanding and analysis of these effects are increasingly important as lasers and other optical devices experience increased use in military applications.

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A Computer Program
for Investigating Atmospheric
Effects on Laser Designators

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis presents a computer program designed to analyze the data from a TV camera for investigating laser beam propagation through the atmosphere. It uses aspects of Fourier optical theory to analyze the TV image to measure the effects of atmospheric disturbance and platform stability on the target spot. The understanding and analysis of these effects are increasingly important as lasers and other optical devices experience increased use in military applications.

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I. INTRODUCTION

A. PROBLEM

A problem has occasionally been experienced in concentrating laser energy from a laser designator onto a target and sufficiently illuminating that target so a weapon sensitive to that illumination will home in on the target. Two circumstances have possibly caused this to happen; the energy is either too diffused at the target to illuminate it properly or the beam partially or completely misses the target. The aim of this study is to develop a computer program to aid in determining which part of these effects is atmospheric and which is the instability of the laser and stabilization system in the illuminating aircraft.

B. METHOD OF APPROACH

The analysis of the problem requires two general types of systems. One system evaluates the performance of the designator using some techniques from Scott [Ref. 1]. A silicon vidicon views the successive pulsed designator spots on the target from a location near the target. A line spread function of the spot on the target and the standard deviation of the wander of the laser beam is produced. The other system provides measurement of C_n^2 for atmospheric turbulence along an optical path adjoining the designator

optical path. The laser on the target is viewed by a silicon vidicon located near the designator's optics. The value of C_n^2 obtained is inherently properly path weighted to express the atmospheric effects on the designator spot. Techniques from Fourier optics theory use the measured value of C_n^2 to predict the intensity pattern of the laser beam on a distant target. The results from the two systems can then be analytically compared to determine the causes of spot wander and broadening.

The sponsor-supplied hardware includes an HP-9825 calculator with 23K bytes of internal memory for equipment control and data processing; an HP-9885 disc memory used for additional storage space; and a Quantex DS-30 Digital Video Analyzer used for digitizing the analog video input from an Eigen video disc; a Panasonic NV-1240 video tape recorder for initial recording of video from the target on a silicon vidicon camera. After analysis, output is in the form of plots produced on an HP-9862 plotter.

The sequence of analysis is currently as follows. Modulation transfer functions (MTF) of the laser output and optics are measured or calculated and stored on disc. A video recording of the target being illuminated by the designator is made for a number of video frames, the target alone is also recorded, for later subtraction from the total picture to produce an image of the laser spot alone. The

video recording is then played through the DS-30, controlled by the HP-9825, to digitize the information for use by the HP-9825. The HP-9825 takes the digitized video of the target, produces a line spread function (LSF) of the image, subtracts the background, and averages a number of frames to produce a short term measurement of the laser energy on the target. The amount that each laser spot wanders from the others is also stored. In the second phase, the HP-9825 uses the MTF's of the laser, optics, and atmospheric measurements to produce a total system predicted MTF, LSF, and wander. These results of the target spot measurement and the baseline studies can be compared for possible correlation.

The laser pulse is timed so that it occurs on the fly-back of the TV signal. This will cause the laser spot to appear on one field of a frame. For accurate results the DS-30 needs to digitize a single field for each pulse of the laser. The videotape unit currently used will not allow this capability. For this reason the tape recording video is transferred to an Eigen video disc, which has the capability of displaying each frame or field (1/2 video frame interlace) individually and of selecting any one frame or field for viewing.

II. BACKGROUND AND PROGRAM DESCRIPTION

A. THEORETICAL DESCRIPTION

In order to combine the individual optical components of the laser to the target system, some elements of Fourier theory must first be remembered. The Fourier transform represents the one dimensional position variable g(y) expressed in the spatial frequency domain U(v). The inverse transform repeats the operation in the opposite direction. Their forms are commonly represented as follows:

$$U(v) = \int_{-\infty}^{\infty} g(y)\exp(-2\pi ivy)dy = \mathcal{F}[g(y)]$$

$$g(y) = \int_{-\infty}^{\infty} U(v)\exp(2\pi ivy)dv = \mathcal{F}^{-1}[U(v)]$$

The program calculates the value of the integral at a preset number of points and yields a discrete Fourier transform. A theorem from Fourier theory that allows us to compute the line spread function as presented in Fried [Ref. 2] for one of the elements in the system given the others is the convolution theorem stated as follows:

If $\mathcal{F}[g(y)] = G(v)$
and $\mathcal{F}[h(y)] = H(v)$
then $\mathcal{F}[g*h] = GH$
(* - convoluted with)

The first element in the system we are analyzing is, of course, the laser itself. The radial intensity output of the laser is generally Gaussian of the form $A=A^{o}\exp(-r^{2}/2\sigma^{2})$ as shown in Figure 1. This can be calculated for each laser for approximate results but was usually measured directly in this study.

The above radial distribution of intensity must then be integrated over x to produce a one dimensional line spread function for the source. A Fourier transform is then used on this LSF to yield the MTF of the laser. The MTF is a measure of the spatial frequency response of a system compared to the input. A "perfect" system response would be 1.0 out to its limit (large spatial frequencies) and then dropping to zero.

The optics associated with the laser is basically diffraction limited. The "Airy function" is used to calculate the diffraction point spread function for the laser optics. This point spread function is then converted to a line spread function, Fourier transformed to get the MTF and then combined by the convolution theorem into a laser system Fourier transform.

The next step is to calculate the effects of atmospheric turbulence on the laser beam. The value of C_n, "the index of refraction turbulence structure constant," as expressed by the relationship from Tatarski [Ref. 3] and Ochs et. al. [Ref. 4]:

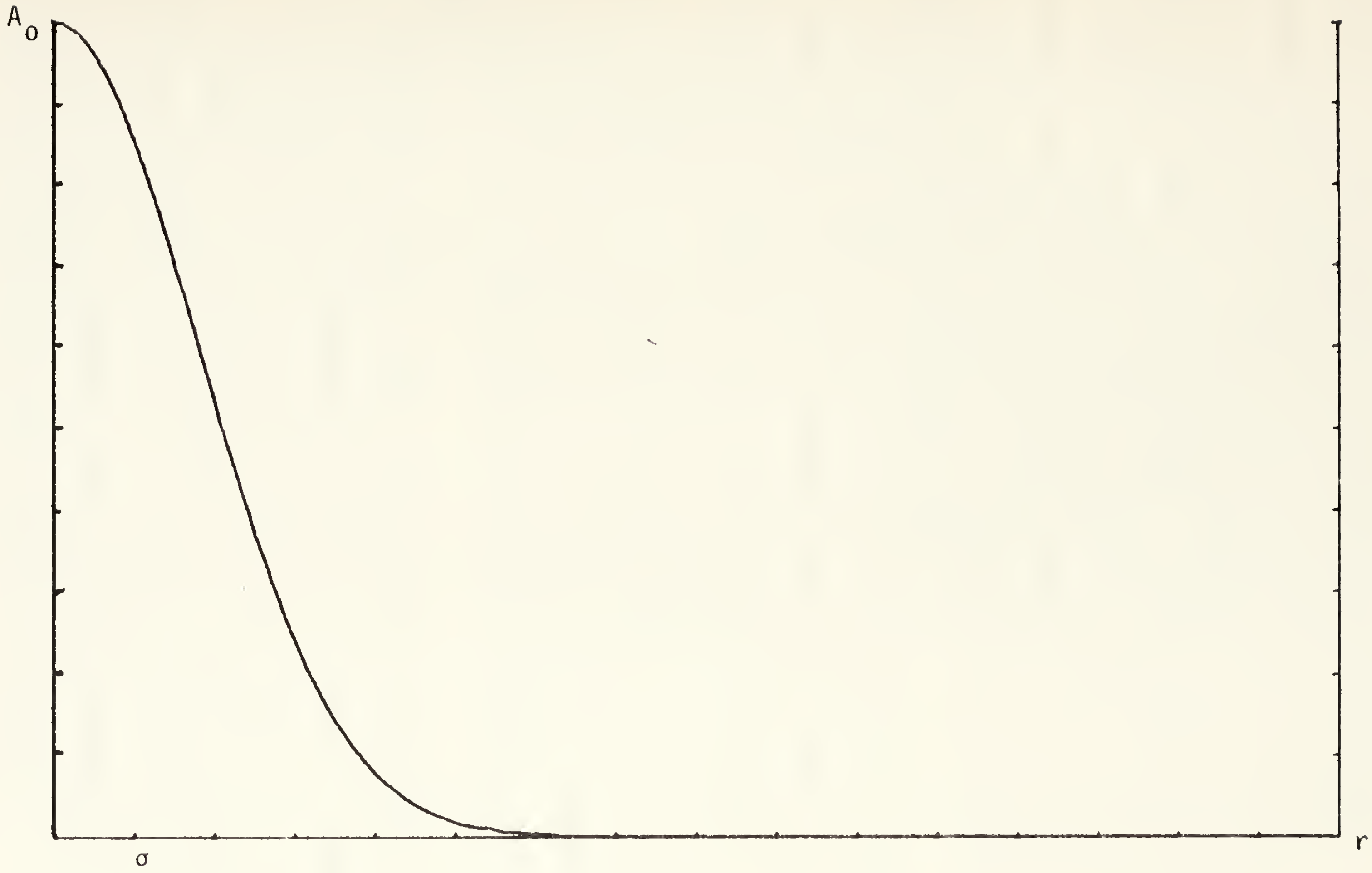

FIGURE 1. IDEAL LASER INTENSITY OUTPUT LINE SPREAD FUNCTION

$$<(T_{r1}-T_{r2})^2> = r^{2/3} C_T 2 \text{ and } C_n = 79 \times 10^{-6} p/T^2 C_T$$

where $T_{r1}-T_{r2}$ is absolute temperature at two points separated by a distance r and p is pressure in millibars; is used to predict the MTF of the atmosphere over the path between the laser and the target. Measurements made along the path are inputs to the C_n equation which predicts the turbulence effects on the MTF and wander of the beam. In the field, however, plans are to measure C_n by optical methods decribed in Crittenden [Ref. 5].

The theory then, according to Fried [Ref. 2], shows that the total effect of the atmosphere and the laser can be found by the product of the two transform functions:

$$G \text{ total } (v) = G \text{ optics}(v) \times G \text{ atm}(v)$$

The inverse transform then will yield the line spread function of the total system, the LSF as predicted on the target.

Crittenden et. al, [Ref. 5] describe the process of converting the one dimensional LSF to a circular symmetric PSF using the Abel transform, from Griem [Ref. 6]. The power inside a circle of radius R can then be obtained by integrating the PSF out to R. For the purposes of comparison in this study, however, the resulting system LSF is used to compare the prediction with measured values.

B. HARDWARE USE AND LIMITATIONS

The HP-9825 calculator used for this program had an internal capacity of 23K bytes. This was quite adequate for program storage but because of the great volume of digitized video data that was involved, the inclusion of an HP-9885 disc drive system was necessary. The Quantex DS-30 can store and rapidly transfer a maximum of 512 lines of video with 512 pixels (picture elements) per line, easily exceeding the HP-9825's memory capability. The large overflow of data was reduced by storing each image into a quarter of the memory, thus limiting the amount of data that needed to be transferred. This also made disc storage more reasonable and sped up program running time.

The DS-30 was also capable of taking the difference on a pixel by pixel basis between a reference image and the input and storing that in memory. Differencing was necessary in order to remove the background from the recorded image for processing the laser spot alone. Normally, it is necessary to divide the image by the background to offset the effect of the non-uniform reflectivity of the target. This was not possible with the DS-30 so these steps need to be performed by the computer. The division was not possible to do at this time because of the memory limitations of the HP-9825. This must be done pixel by pixel since division by the LSF is not equivalent. The memory limitation was also the

reason why the HP-9825 used the LSF instead of pixel by pixel subtraction for this process.

All the peripheral equipment to the HP-9825 was controlled through an IEEE standard 8 bit interface bus. This allowed control of all aspects of data acquisition and processing to be modified by software. The video recorders were the exception to this and provided the only real manual manipulations required after the program had begun. Each frame of video needed by the program had to be selected when requested by the program because of the lack of interface control.

The linearity of the recording system was checked and found to be almost distortion free. A signal from an image was passed directly to an oscilloscope from the vidicon and compared side by side to a signal from the same image which had been recorded in the tape recorder, transferred to the video disc and then passed through the DS-30 circuitry to a digital analog converter for viewing. Crittenden et. al. [Ref. 7] present photographs of the two images for comparison and further discussion.

Variable usage became a problem as the program grew, which was due to the limitations of the HP-9825. The HP-9825 has available twenty-six variables (A-Z), twenty-six variables for arrays (A-Z), a subscripted variable (r) with as many elements as the memory has space for plus a

subprogram variable (p) for use in passing parameters through "called" subprograms. One of the usage problems was using identifiable variables in passing from main programs to subprograms. A good number of the subprograms originally were designed for other programs and the variables often conflicted. The r variable is nice to use here because of its practically unlimited numbers. A more serious problem, though, was the inability of HPL, Hewlett Packard's version of the Basic language, to allow an entire array to be used as a parameter to pass to a subprogram. This at first made necessary extra internal storage for additional arrays to be used only within a certain subprogram, with the variable name being changed through a lengthy process upon entering or leaving that subprogram. A much faster and easier way was using separate storage files on the disc for each major array manipulation. When entry into a subprogram was needed the array could be stored in the file assigned to that subprogram, which could then be read out and labelled as any array needed for each subprogram.

The programming to use the DS-30 also was primarily a language problem. The DS-30 was very sensitive to the format in which it received data or commands. All leading zeroes and carriage return/line feed commands had to be suppressed. The address of command locations within the DS-30 also had to be encoded in hexadecimal nibbles (one-

half byte) and sent in reverse order to load the registers properly. Commands to the DS-30 were sent as ASCII character strings. Data was output from the DS-30 to the HP-9825 via a fast read buffer which allowed a very fast data transfer rate. In use, a block of 256 bytes at a time were transferred representing one horizontal TV line of the quartered memory space. This was done in a loop which went back and took 256 lines, completely transferring the image.

It was decided that output would be on the HP-9825 plotter so that direct visual comparisons could be made between measured and predicted intensity LSF's. This was much more dramatic and easier to see than tabular output which then would have to be compared on a point by point basis for a correlation.

III. CONCLUSION

This program can be useful in solving the problem that spurred this study. It will be able to show how much wander can be expected out of a laser designator beam as it travels through the atmosphere from the laser to the target. Based on the video recording of the actual image on a target it will show comparatively the amount of wander actually present in the laser. Plans are to unfold the results analytically, but at present, a visual comparison of the measured and predicted patterns is made to determine if there is any excess wander or "jitter" attributable to the laser platform itself. This determination will be helpful in setting specifications for the stability needed in the system to remove as much excessive spot movement as possible. It will also allow testing to determine if those specifications are being met.

This program can also be used to verify atmospheric problems when both the laser and target spot are fixed and known. Essentially, any of the laser to target elements can be determined by knowing the others and calculating the unknown using adaptations of the program. The beginning part of this program can be used to digitize and store any video image and produce an LSF of the image. This may be

useful in recording and testing the output of several different lasers and optical aperatures for comparative analysis.

This computer program was designed in the initial stages of a continuing project studying the described problem. If desired, changes can be made to the program to adapt to changing field conditions and analysis requirements. In particular, the program now requires a greater understanding of its internal operations and operator interaction than is necessarily needed. More complete cueing prompts and data entry parameters may be worthwhile changes. Adaptability to other hardware may provide more program control, especially if control of the video disc or tape can be handled through an interface bus instead of manually. Also, improvements in output design can be foreseen to expand its usefulness and adaptability.

Finally, the speed of program operation could be increased through use of a faster computer with a greater memory capacity. The HP-9825 is comparatively slow and has insufficient memory. The use of a faster system such as the HP-1000 is recommended for actual measurements.

APPENDIX A

USING THE COMPUTER PROGRAM

The analysis program requires considerable preliminary set up and operator interaction. Before the program is started there should be several items already recorded on videotape. The first item is a TV camera shot of the laser output. This is normally taken with a long focal length lens and filters to reduce the intensity without losing the beam pattern. A part of this recording should include a known diffraction grating through which the beam passes in order to measure the scale of the data for each system of lenses used. The diffraction pattern should extend in the vertical as seen on a TV screen for proper output on the plotter. Also needed to be recorded is, of course, a sequence of laser spot images on the target. Part of this recording should have the target only as a background reference for later calculations.

The next step that needs to be taken is to compute and record the square atmospheric turbulence index (C_n^2), then record the following system data for later program entry; wavelength of the laser, diameter of the optics objective lens, ratio of the obscuration to the diameter of the objective lens, distance to the target, and the extinction coefficient.

The first cue the program asks is for the input/output parameters. Table 1 lists the parameters and the different function each one is used for.

If the laser source pattern is not to be computed the next cue requests that the laser pattern be displayed from the video disc for transfer to HP-9825 memory. A cue is also presented asking for the horizontal width of the images to be taken from the DS-30. The first value should be the left most pixel desired, the second being the furthest right pixel to be used. The first value must be less than the second, with the first no less than 1 and the second no more than 256. This cue is also presented below before either the scale image or the target image is taken.

If the scale of the source data is to be determined the next cue requests that a frame be displayed on the video disc of the laser output with the diffraction grating in place. When this has been done continue the program and it will plot out an LSF of that image whereby the scale of the data can be determined in microradians per point.

The next cue alerts the operator to ensure that a frame of background video is displayed from the video disc for use in the difference process.

The program will then ask for the number of total frames that the user wishes to average for the measured target spot LSF. The value should be in the range from 1 to 600. The

latter value being the greatest number of frames the video disc can hold at one time. The program will then proceed to record and process images from the video disc and DS-30. The program will provide a cue when it wants the next image to be sequenced on the video disc.

The program will alert the operator when it is about to produce a plot. If the HP-9862 plotter is not ready simply stop the program until a piece of plotting paper is in place.

The program will request the system data after the measured image spot data has been plotted. The data format is not critical but should be in the correct units as follows:

Wavelength	Meters
Diameter of objective lens	Meters
Obscuration/objective	None
Scale of data	Microrads per point
Range to target	Meters
C_n^2	Meters$^{-2/3}$
Extinction coefficient	Inverse meters

If the source pattern is to be computed the program requests peak amplitude and standard deviation of the intensity distribution.

The program will then continue computations without further inputs until it has run through with the initial parameters. The I/O parameters will determine at which steps output is plotted. After one run through, the program will request a new C_n^2, range, and coefficient. If the input range is positive the program will again run through from the atmospheric calculations with the new range. If the range is negative, the branch is to the beginning of the prediction phase where all new system inputs are requested. If the range input is zero, the program ends.

APPENDIX B

PROGRAM VERIFICATION AND FLOWCHARTS

I. MEASUREMENT PHASE

Section I (steps 0 - 50) consisted of program setup information and the DS-30 function command programming. This section was easily verified by observing that all initializing functions were accomplished and the response of the DS-30 could be visually noted.

Section II (steps 51 - 86) consisted of transferring the contents of the four quarters of the DS-30's memory to the HP-9825 and producing an LSF of each image. For testing, an image consisting of all black (8 bit binary ones) or all white (8 bit binary zeroes) was placed in each of the four quarters of memory, each quadrant was then read out to the HP-9825. The values received by the HP-9825 corresponded to the contents of the DS-30 memory quadrant and did show proper changes when the subject quadrant memory was inverted from black to white. The LSF was produced by averaging the pixels in each horizontal line of video, each line producing a point value as the image was scanned vertically from top to bottom. Examples of LSF's produced for a "black" and a "white" image are in Figures 2 and 3.

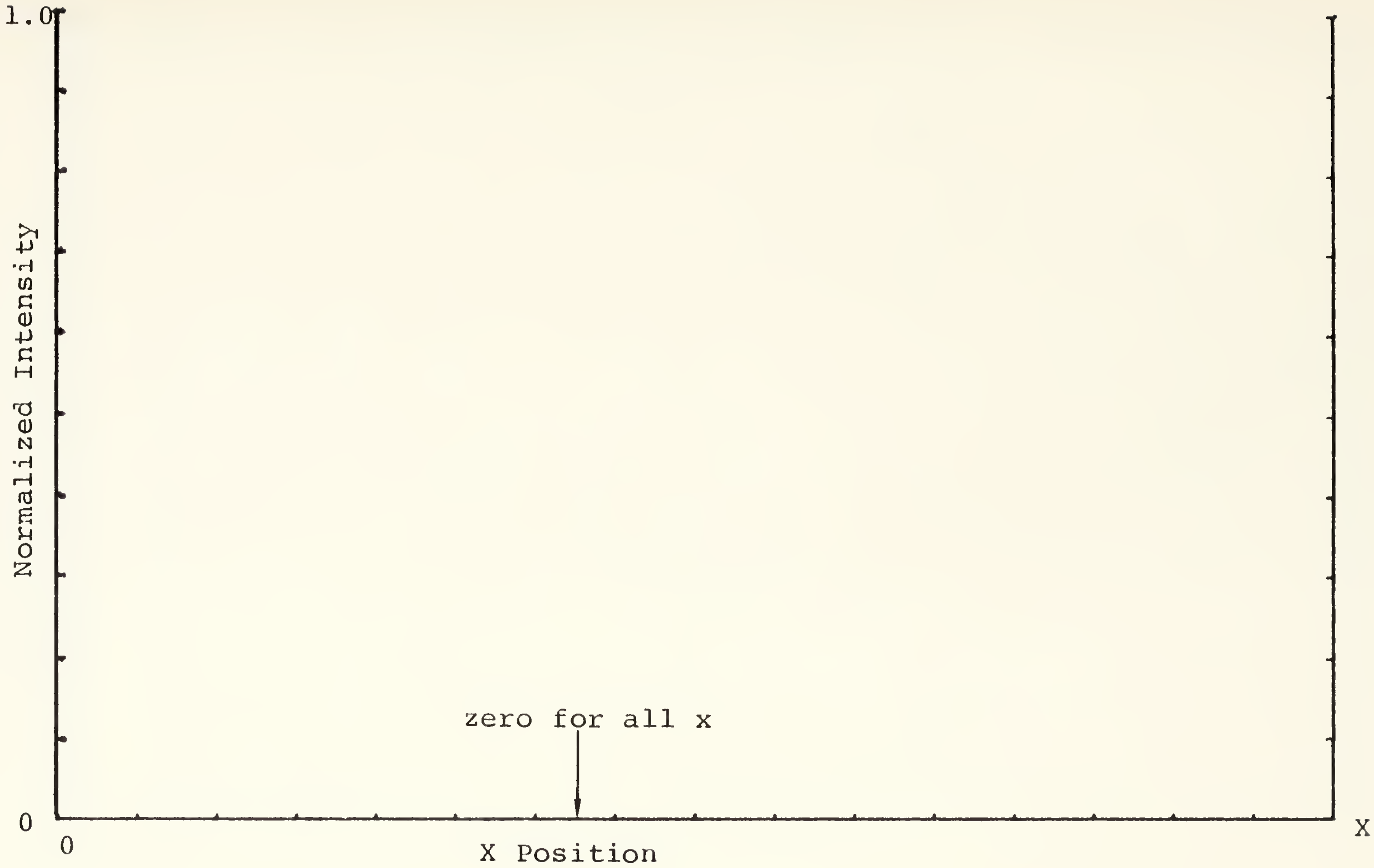

FIGURE 2. "BLACK" IMAGE LSF

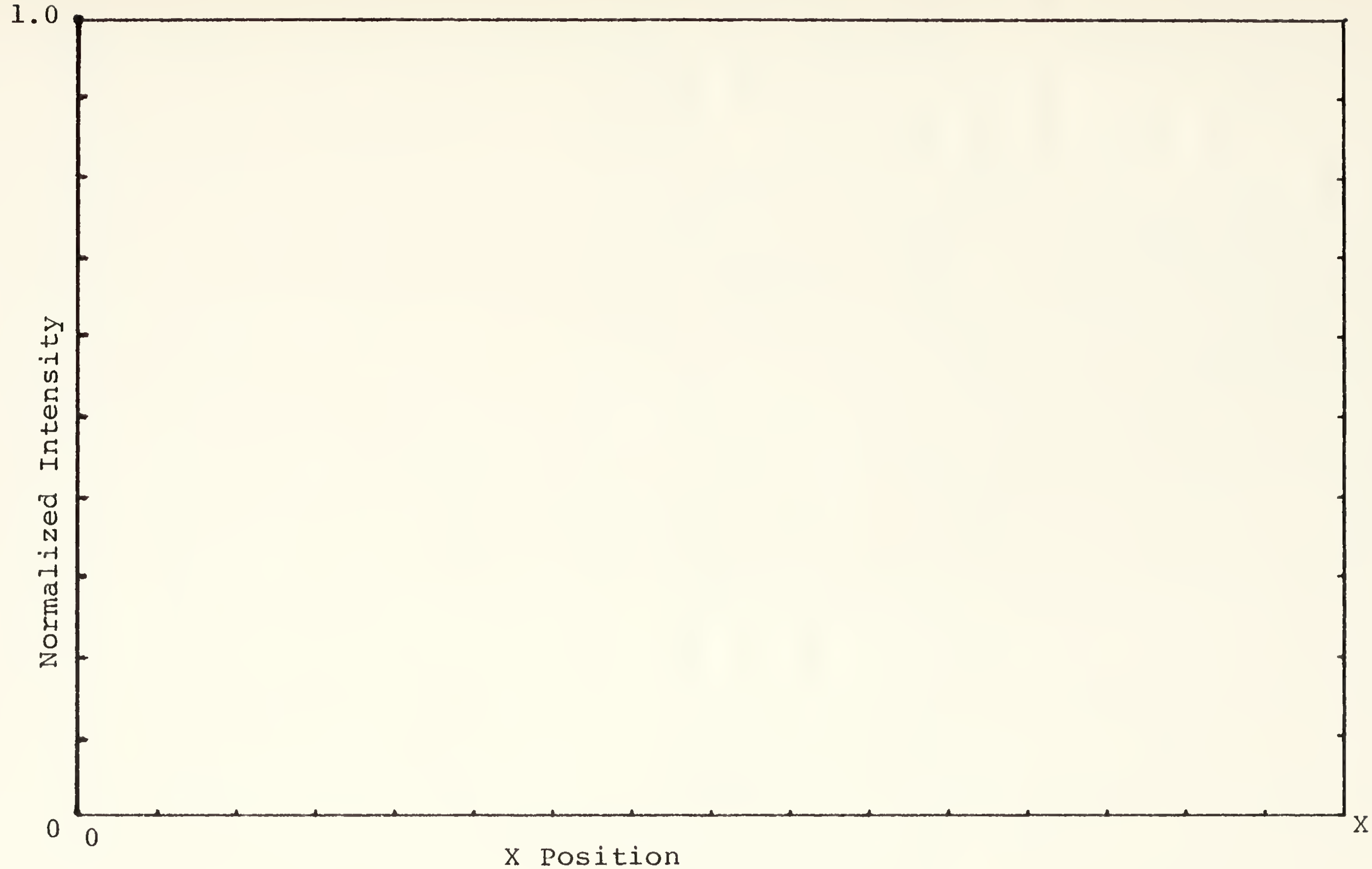

FIGURE 3. "WHITE" IMAGE LSF

Section III (steps 87 - 118) subtracted a reference background from an image to yield a difference image, then shifted the resulting LSF so that the center of area under each image was centered on zero. In this way the wander from each succeeding image could be determined, removed, and the total frames used could then be averaged to show the short term atmospheric action on the laser spot image. Proper operation of this section can be seen in Figure 4 where two images of slightly different position and intensity were averaged to yield an LSF halfway between the two image functions as expected. Figure 5 shows a differenced LSF where a small laser spot was added to a reference background. The result is almost entirely the laser spot with a small amount of "video noise" caused by the camera and associated electronics.

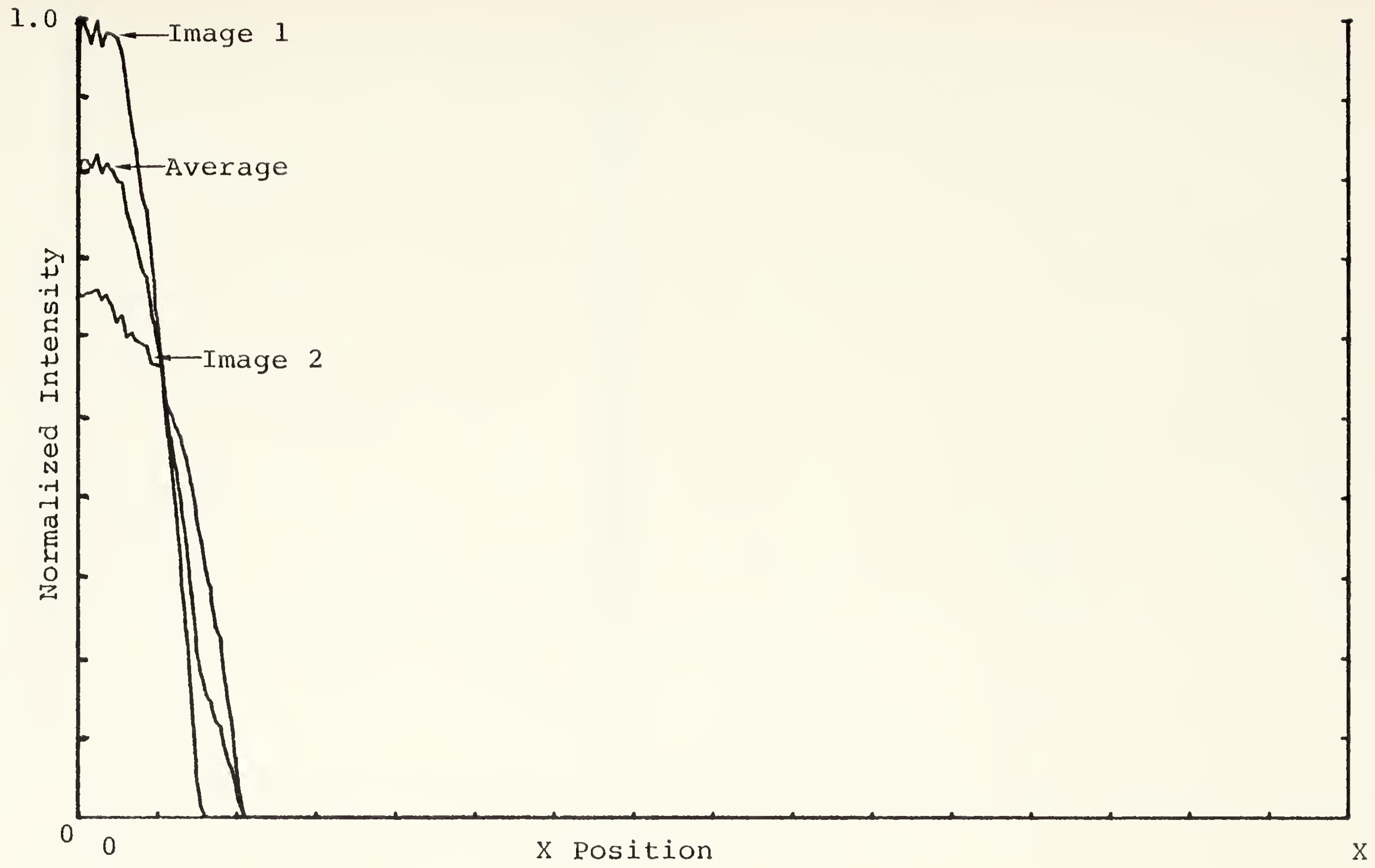

FIGURE 4. AVERAGING EXAMPLE

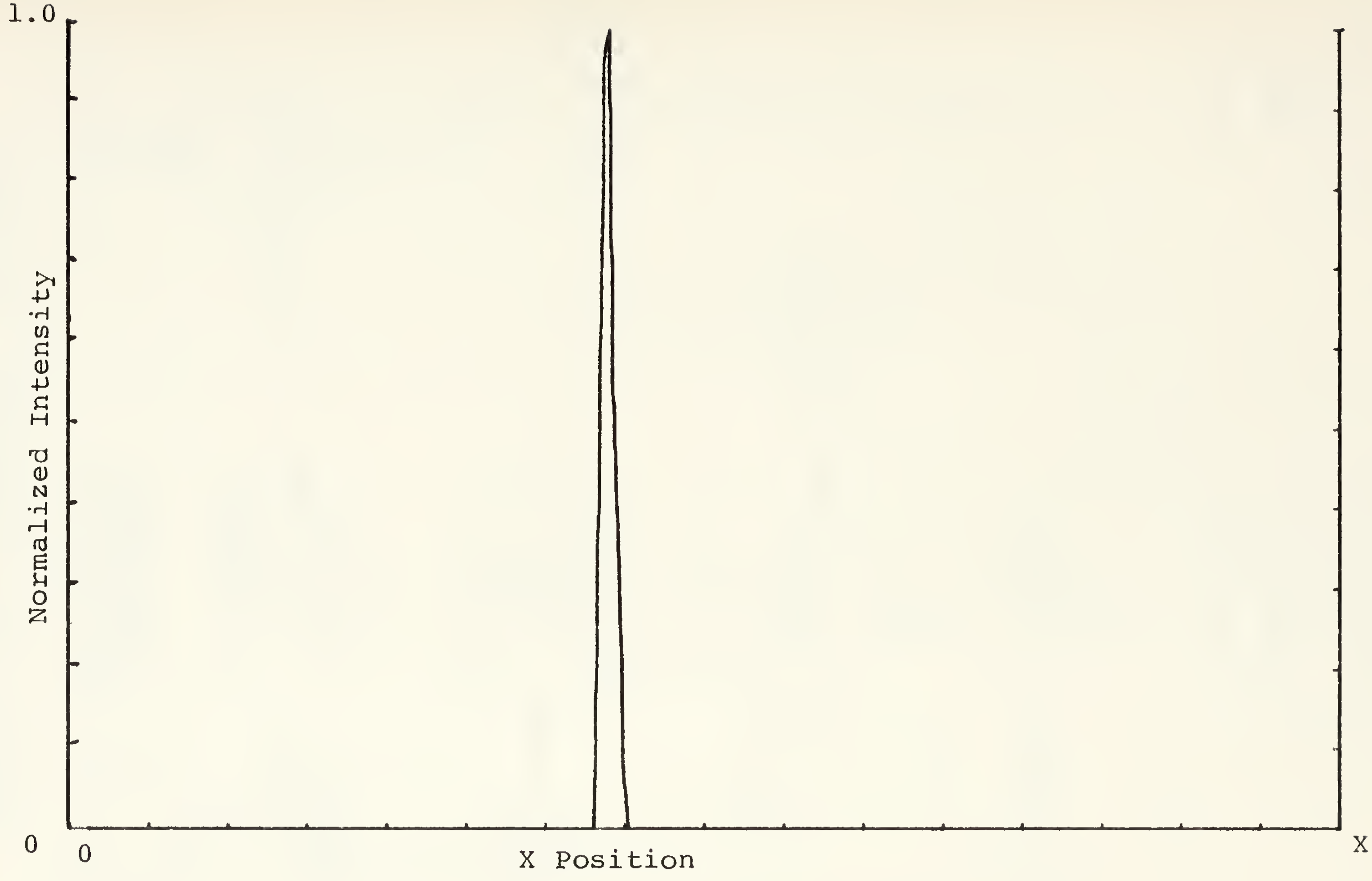

FIGURE 5. LASER SPOT LSF

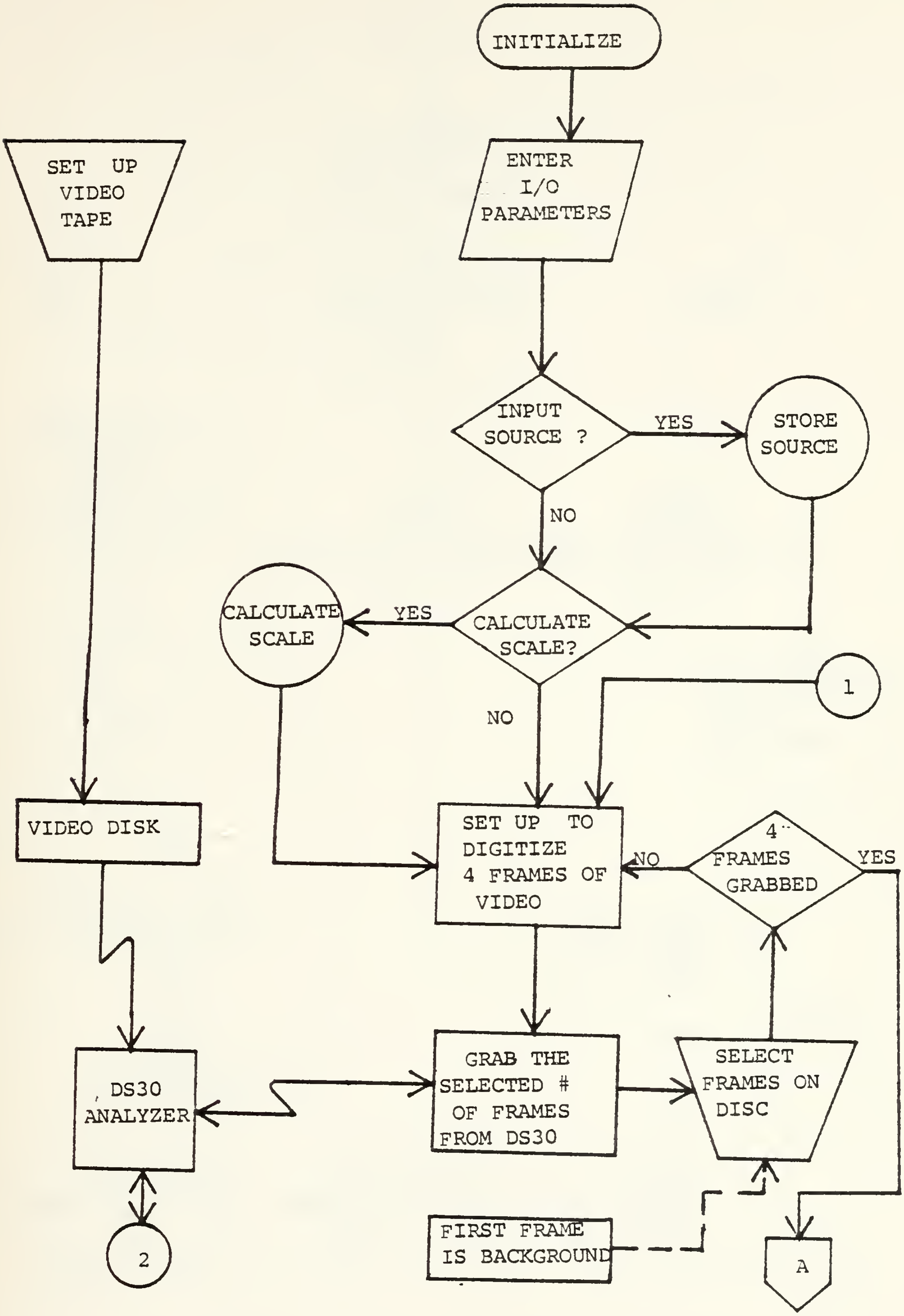

FIGURE 6A. MEASUREMENT PHASE FLOWCHART

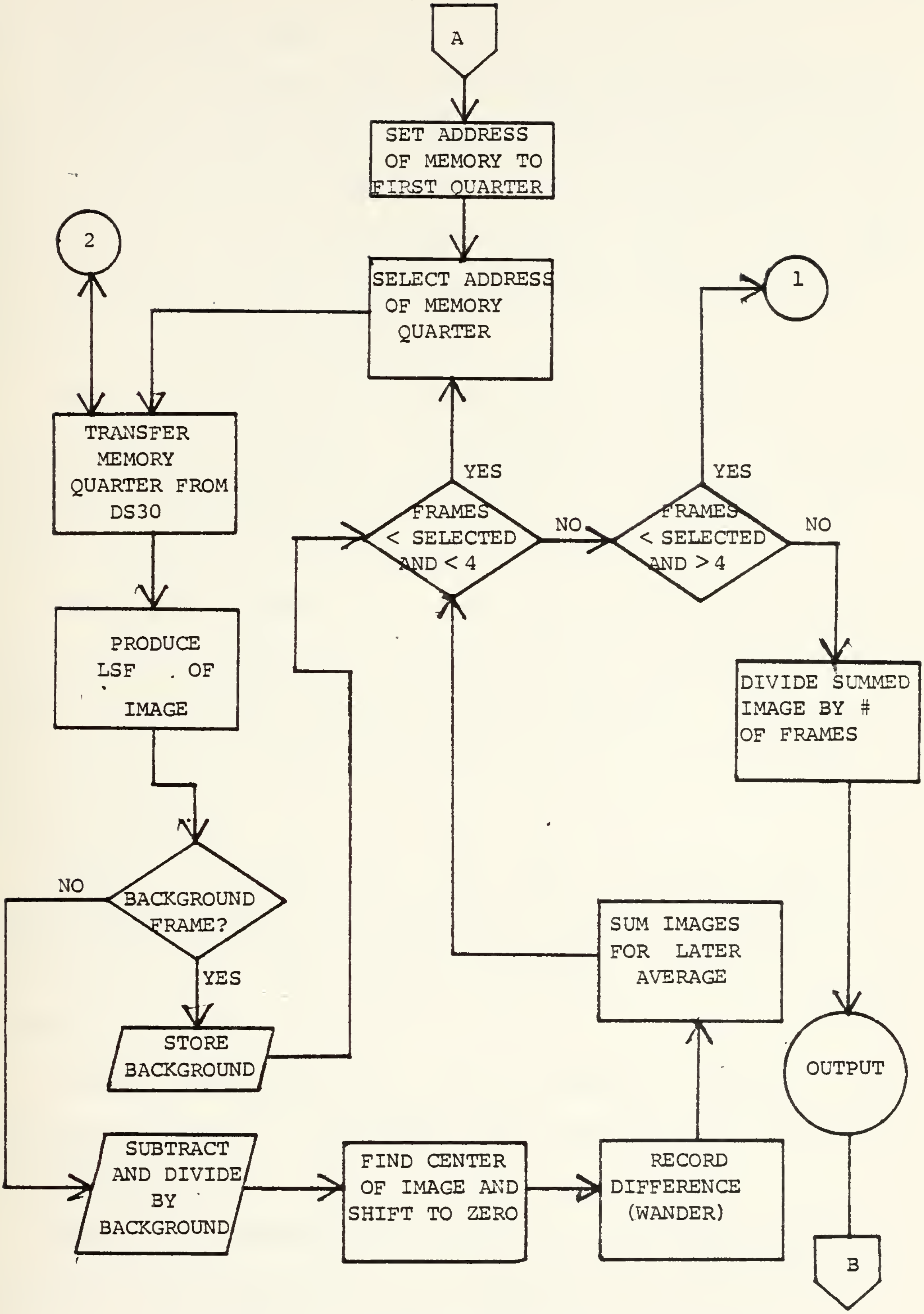

FIGURE 6B. MEASUREMENT PHASE FLOWCHART

II. PREDICTION PHASE

Section IV (steps 119 - 139) enters the parameters of the atmosphere and optics needed to model and predict the laser spot pattern on the target. This section also yields the calculated Gaussian laser intensity output if that data is not measured in the next section. The output of this section is shown in Figure 7.

Section V (steps 140 - 172) consists mainly of branching, data reading, and subroutine action. These subroutines, branching and data input will be verified with proper operation of the program as a whole.

Section VI (steps 173 - 183) calculates the diffraction limited optics effect on the laser output and produces a radial point spread function of the intensity. The output for a point source should be an airy function as results show in Figure 8.

Section VII (steps 184 - 204) again consists mainly of subprograms and also calculates the product of the calculated optics and laser output transforms. The output is in Figure 9.

Section VIII (steps 205 - 220) computes the MTF of the atmosphere based on the inputs from Section IV. The output is in Figure 10.

Section IX (steps 221 to the end of the main program) is mainly subprogram action in computing the final LSF

predicted on the target using the source, optics and atmospheric MTF's. It also provides a link to re-enter the program for changed parameters. The output of this section is listed under the subprograms used.

FIGURE 7. EXAMPLE OF CALCULATED LASER OUTPUT

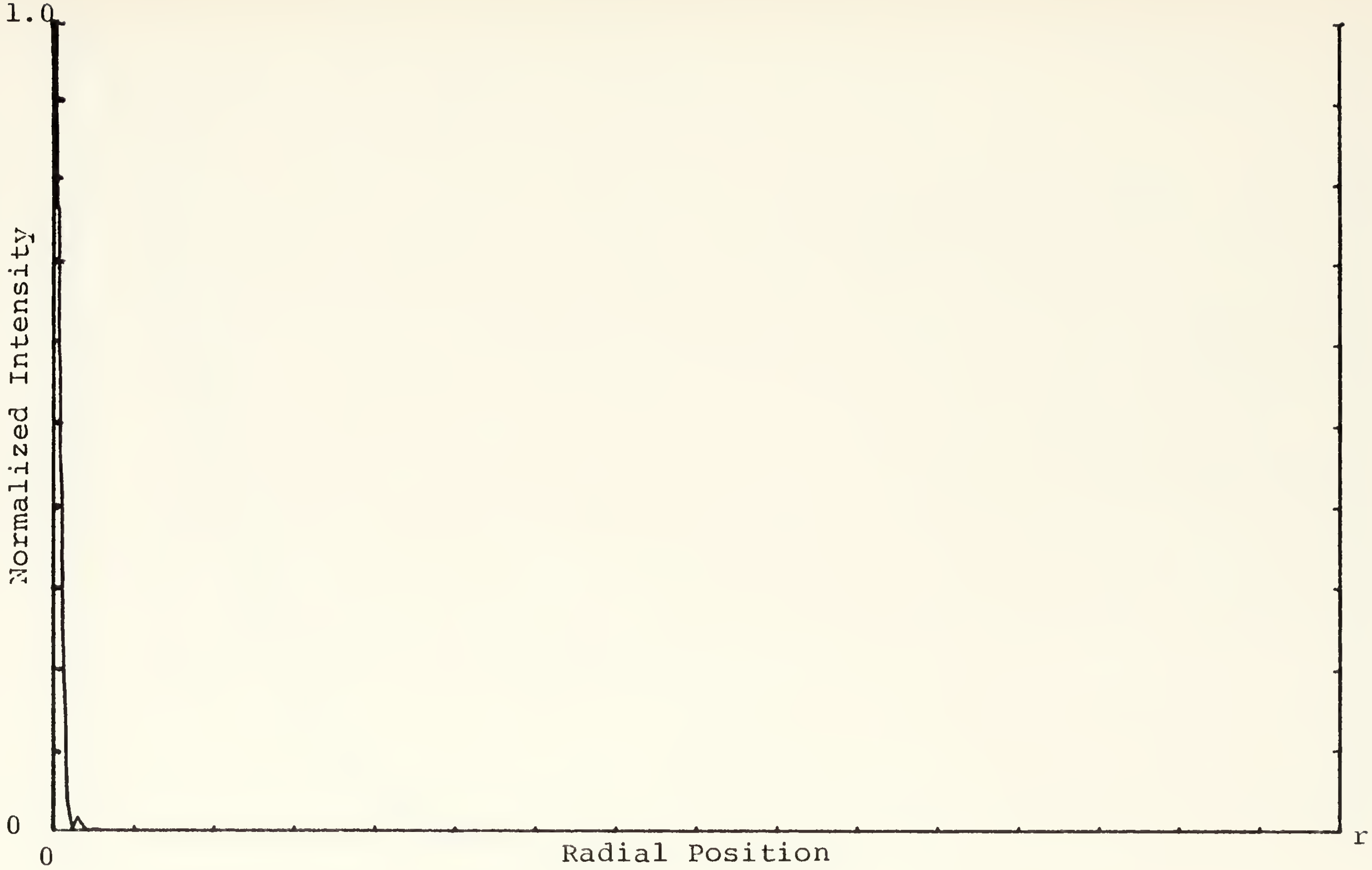

FIGURE 8. OPTICS OUTPUT

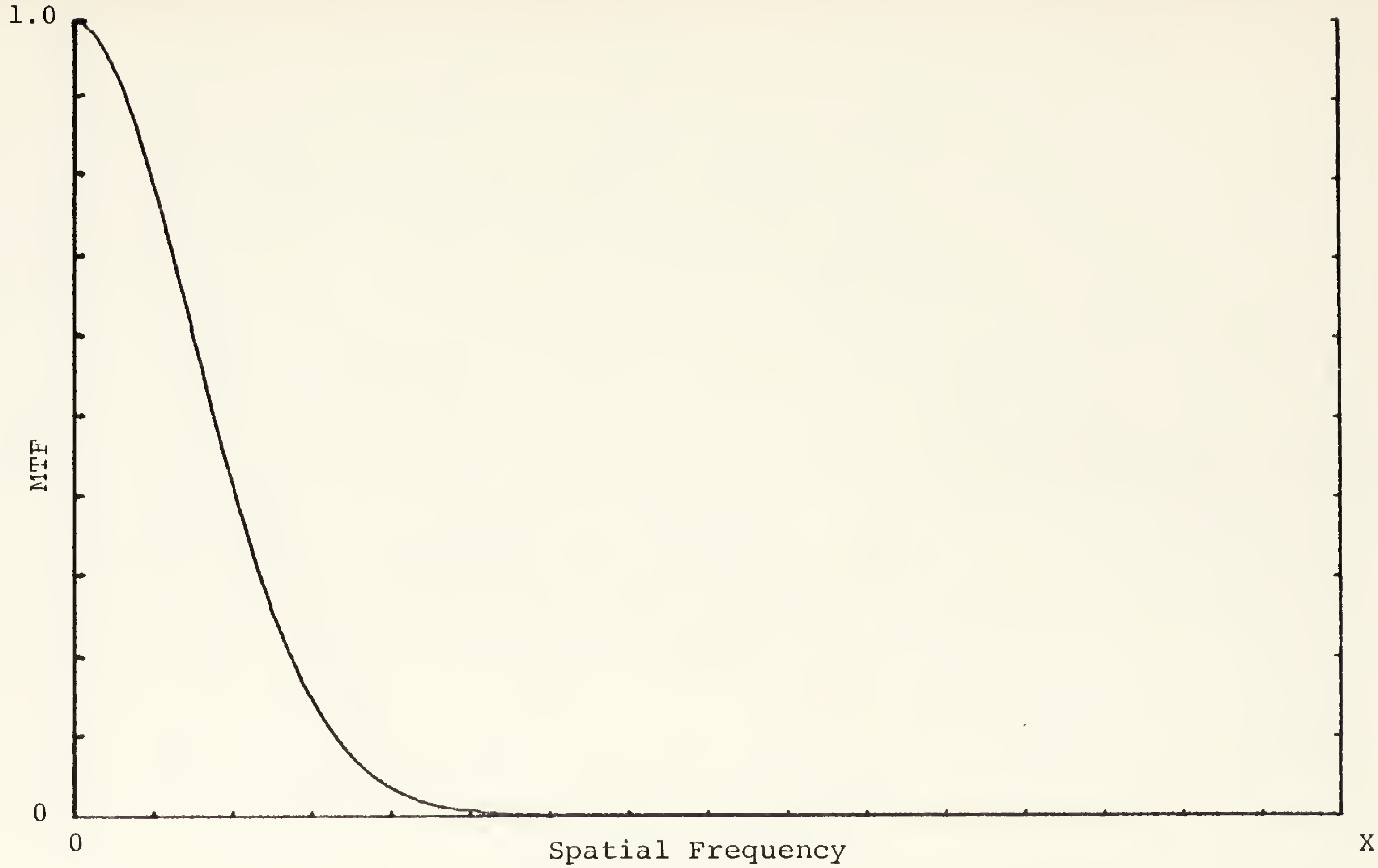

FIGURE 9. LASER AND OPTICS MTF

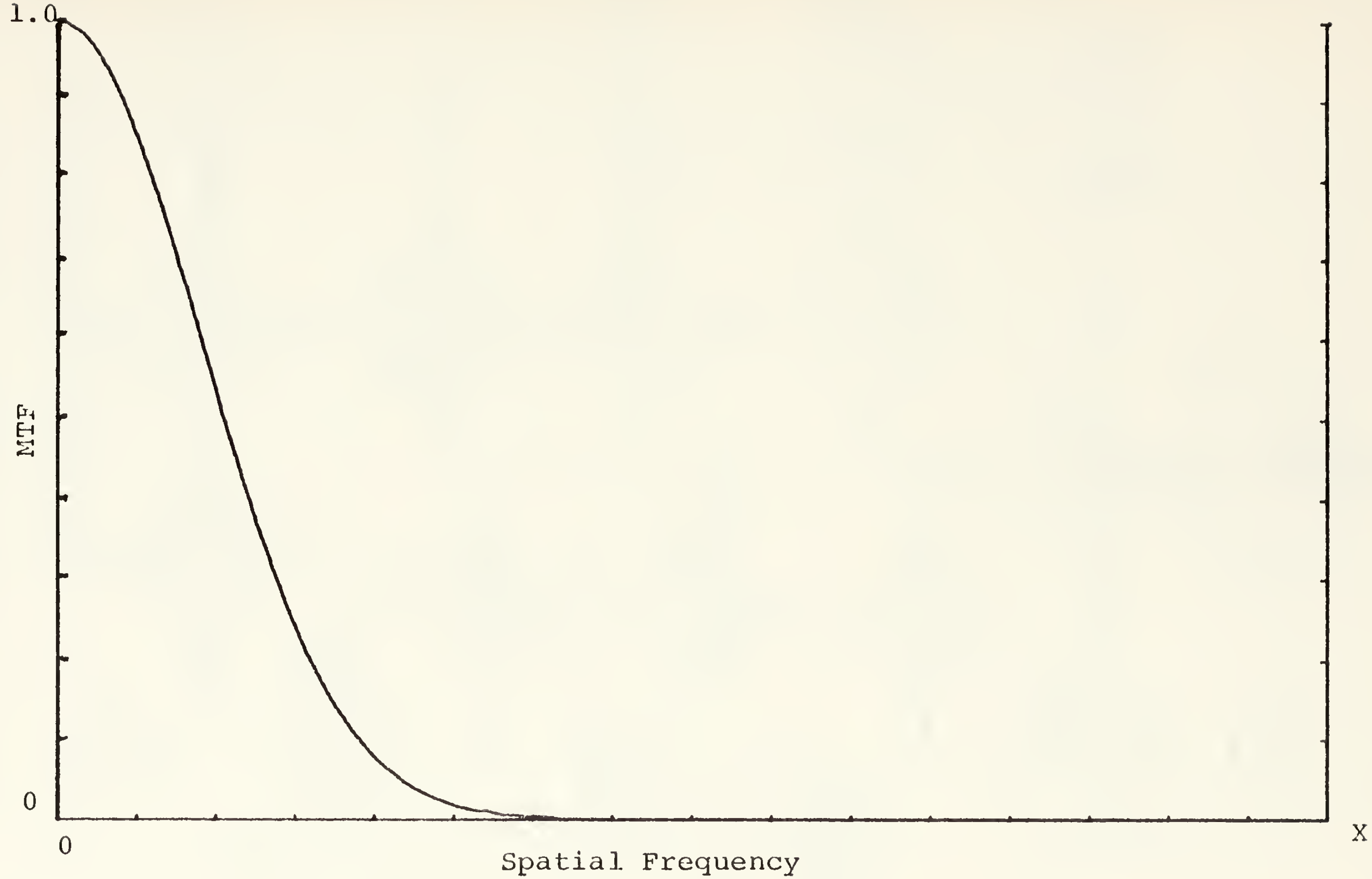

FIGURE 10. MTF OF THE ATMOSPHERE (SHORT TERM)

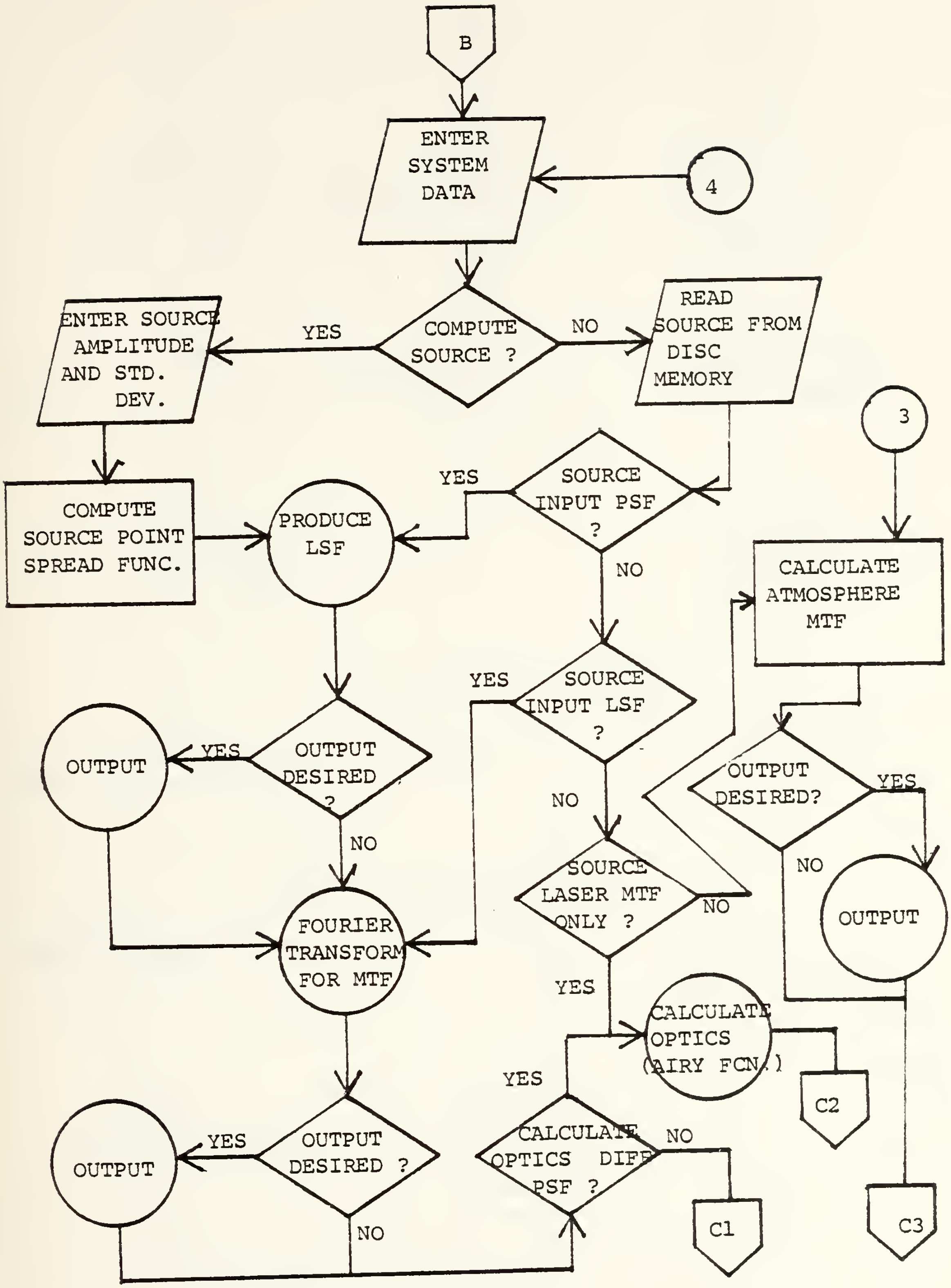

FIGURE 11A. PREDICTION PHASE FLOWCHART

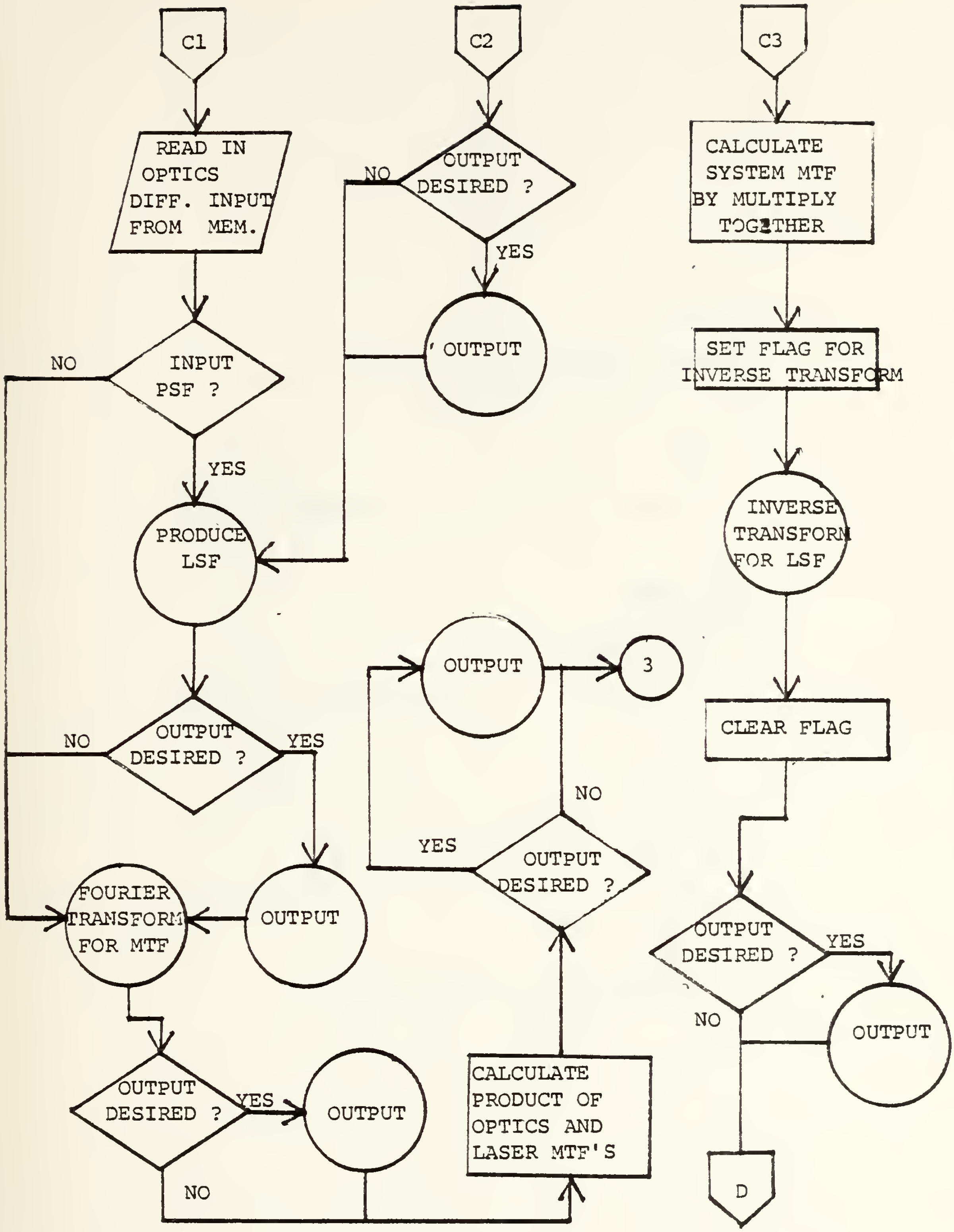

FIGURE 113. PREDICTION PHASE FLOWCHART

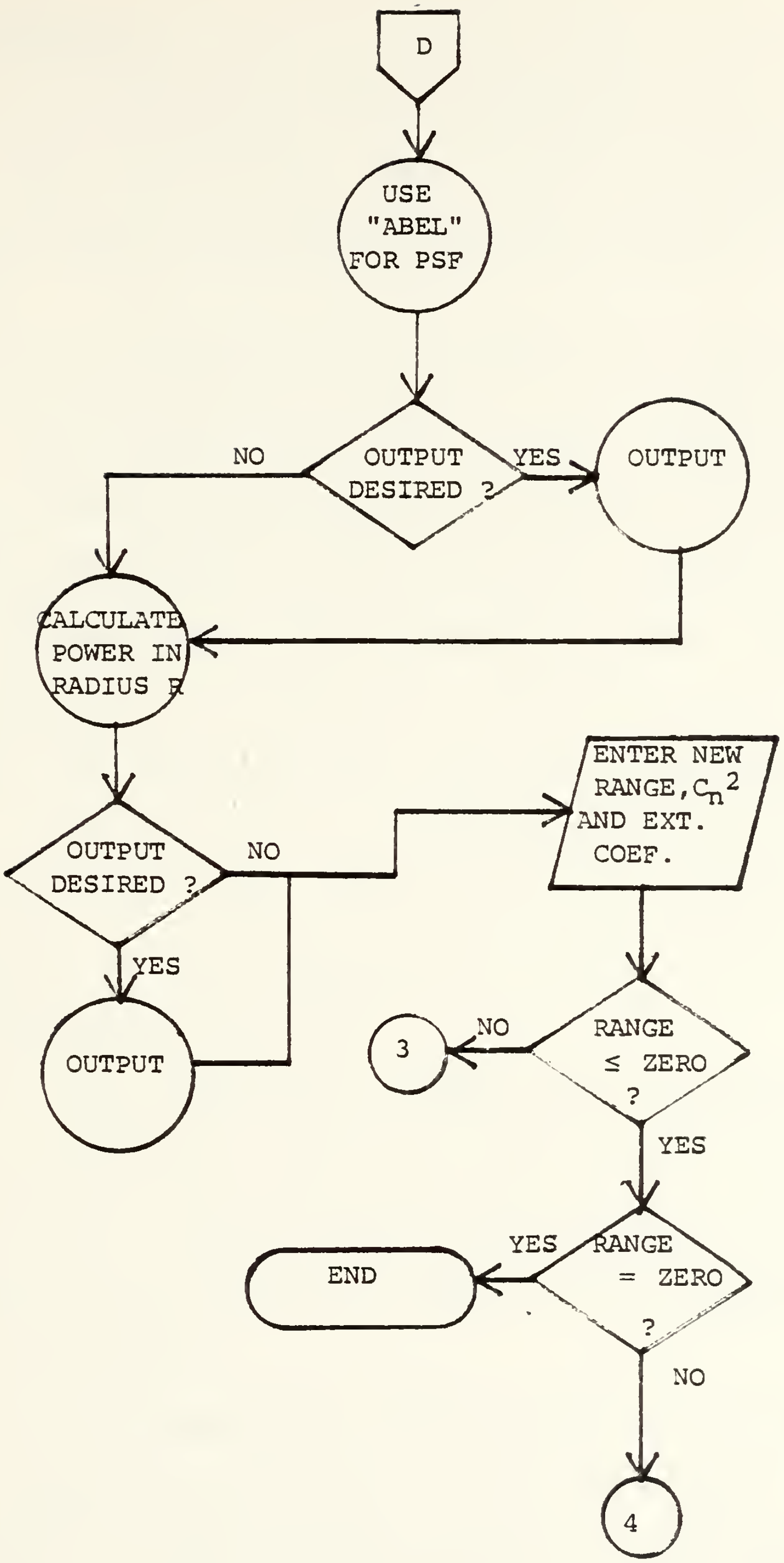

FIGURE 11C. PREDICTION PHASE FLOWCHART

III. SUBPROGRAMS

Section X (subprogram ABEL) produces a point spread function (PSF) from the LSF computed for the target laser spot. The input and resulting output is shown in Figures 12 and 13.

Section XI (subprogram LSF) enables the program to compute a line spread function for later conversion to a MTF when the input is calculated by Sections IV and VI as point spread functions or when the data is input in Section V in the point spread function format. Sample input and output is in Figures 14 and 15.

Section XII (subprogram B) calculates the fraction of the power inside a circle of a chosen radius about the center of the laser spot. This is helpful in determining if the spot is intense enough on the target. The input and output are Figures 16 and 17.

Section XIII (subprogram FXFORM) is a discrete Fourier transform program that functions both as direct and inverse depending on the flag set in the main programs. Several Fourier pairs were checked to ensure correct calculations, Figures 18 through 21.

Section XIV (subprogram SOURCE) digitizes an image of the laser source for inclusion in the prediction calculations. It is a storage of DS-30 video from the Vidicon camera input.

Section XV (subprogram SCALE) digitizes an image with a standard diffraction grating for calculating the scale of the data. Figure 22 is an example of this image.

Section XVI (subprogram OUTPUT) yields in useable form all the data required for analysis. This subprogram was used for all the output in the plot format. Functions "MIN" and "MAX" are used by the "OUTPUT" subprogram.

The program was run as a whole numerous times with different I/O parameters and data in order to exercise the branching combinations and program steps. Table 1 lists the I/O parameters available and their uses. This operation was simply to ensure the program ran as was intended.

FIGURE 12. "ABEL" INPUT (LSF)

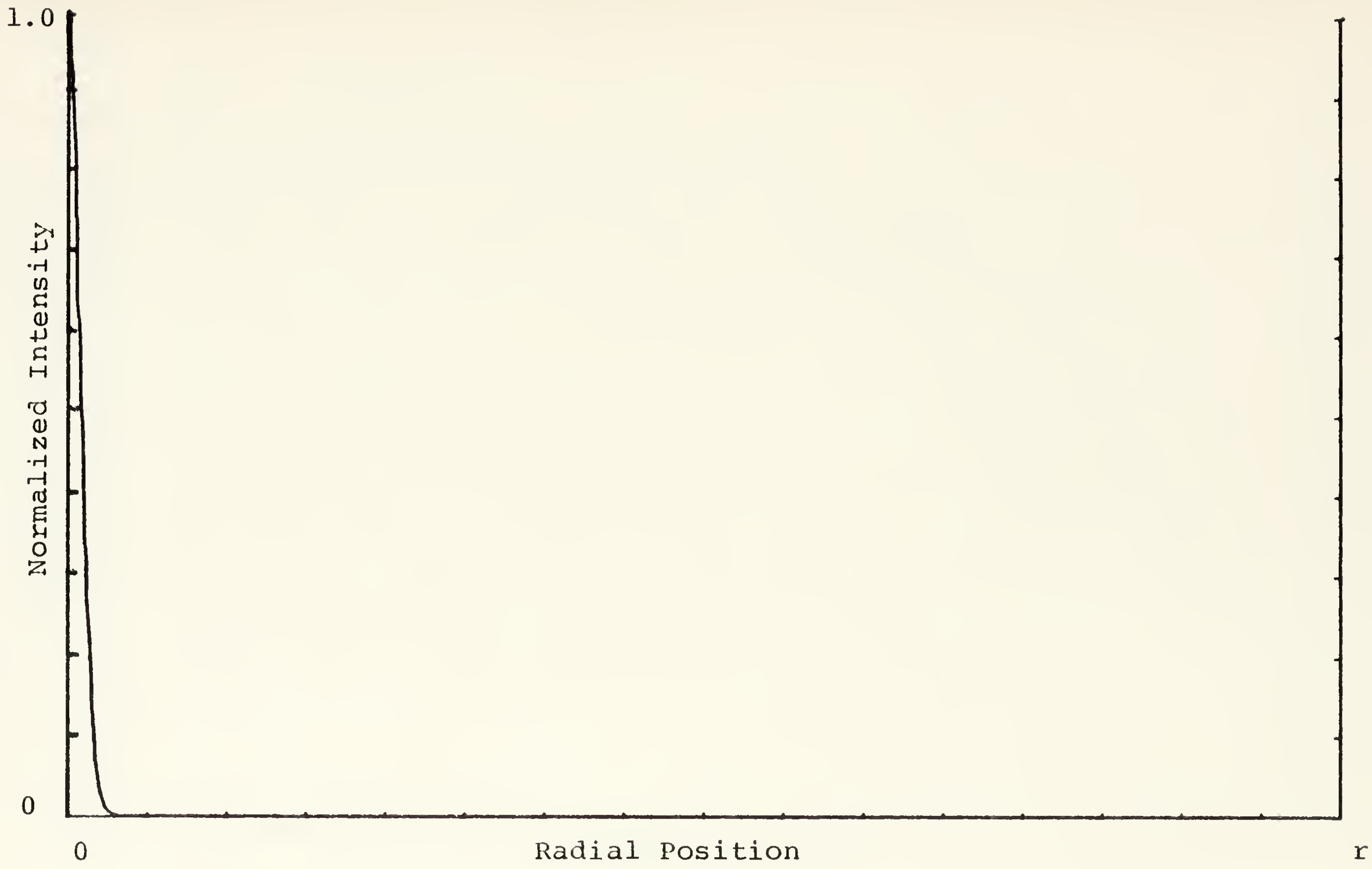

FIGURE 13. "ABEL" OUTPUT (PSF)

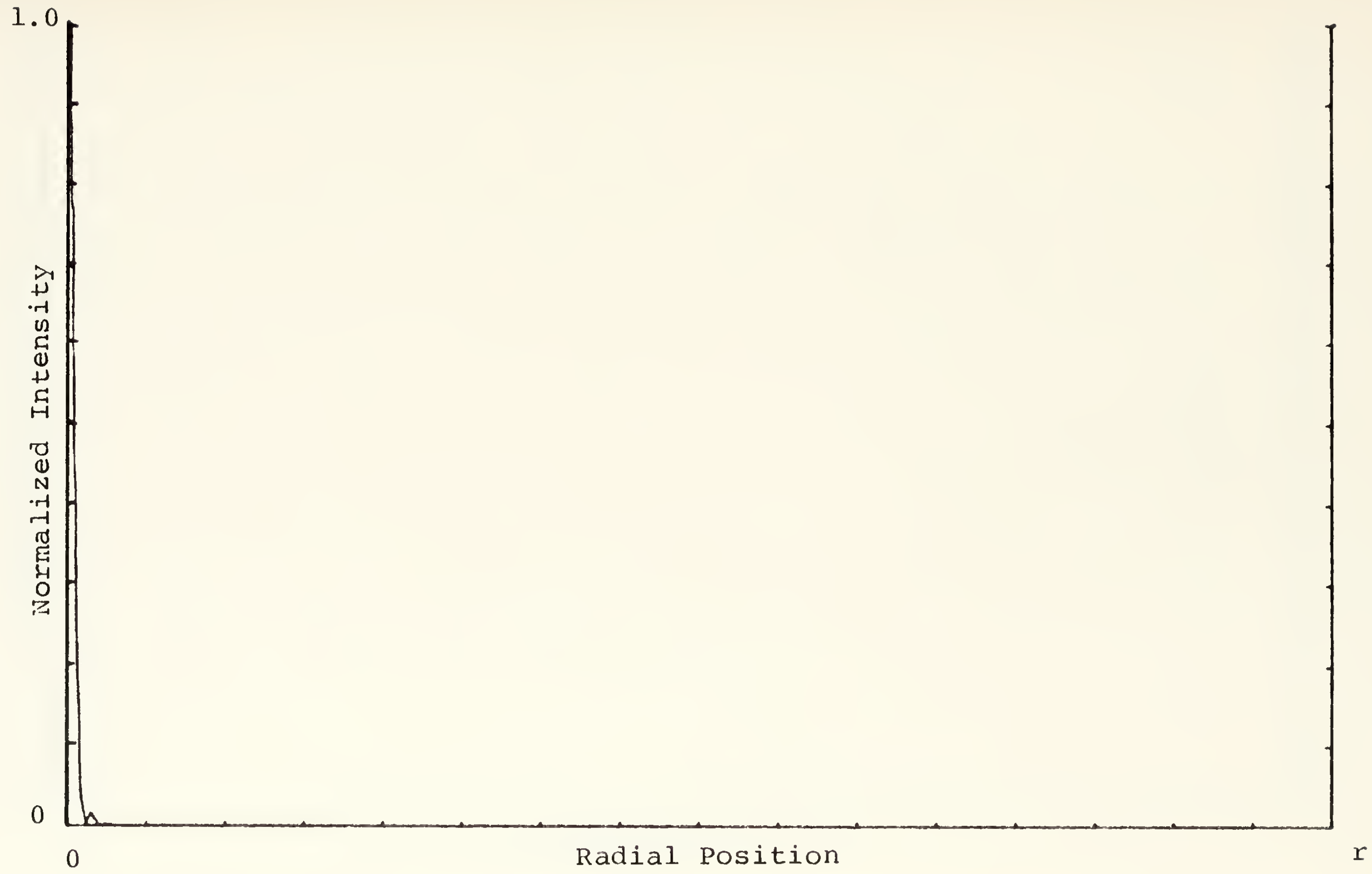

FIGURE 14. "LSF" INPUT EXAMPLE

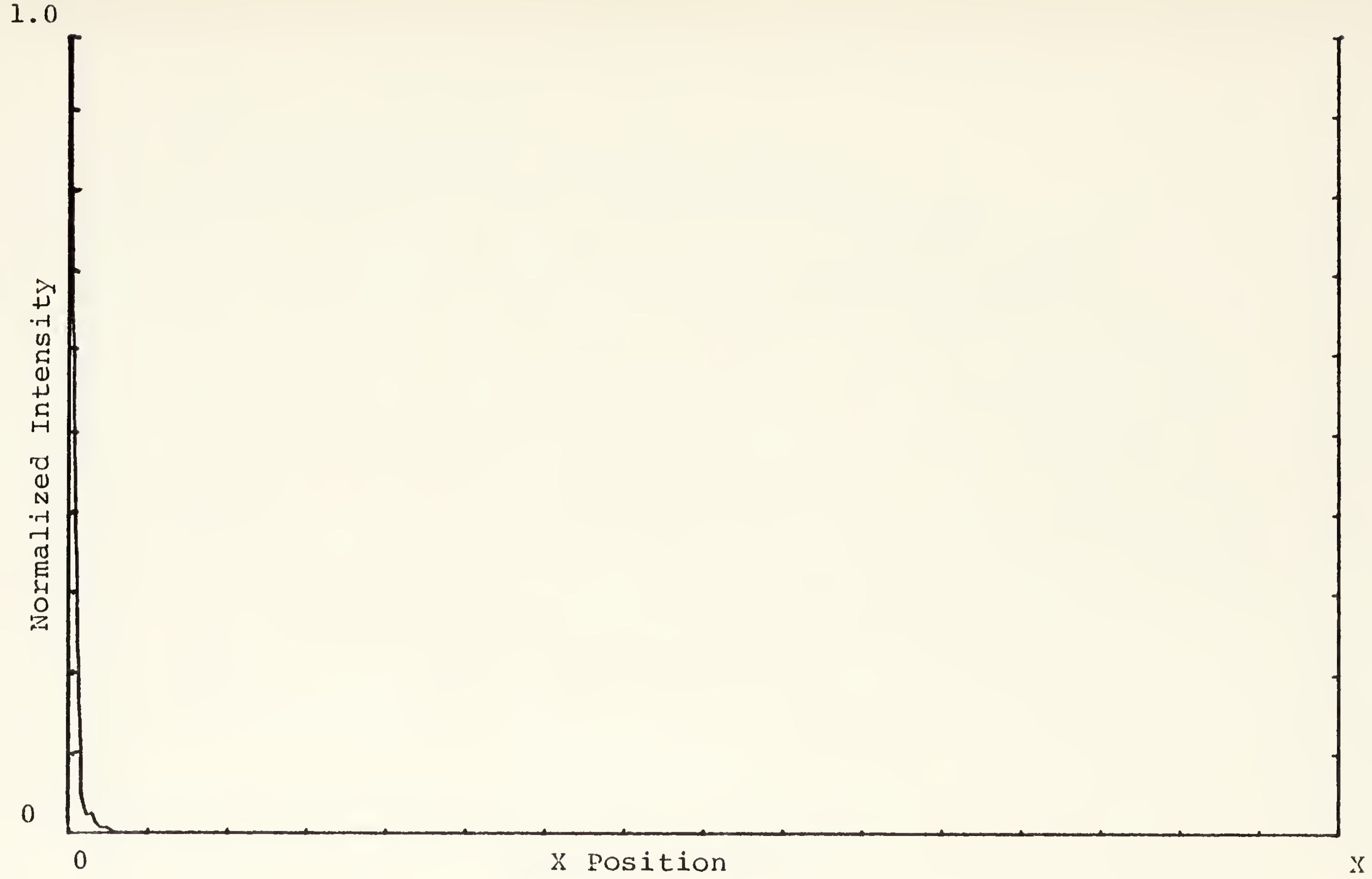

FIGURE 15. "LSF" OUTPUT

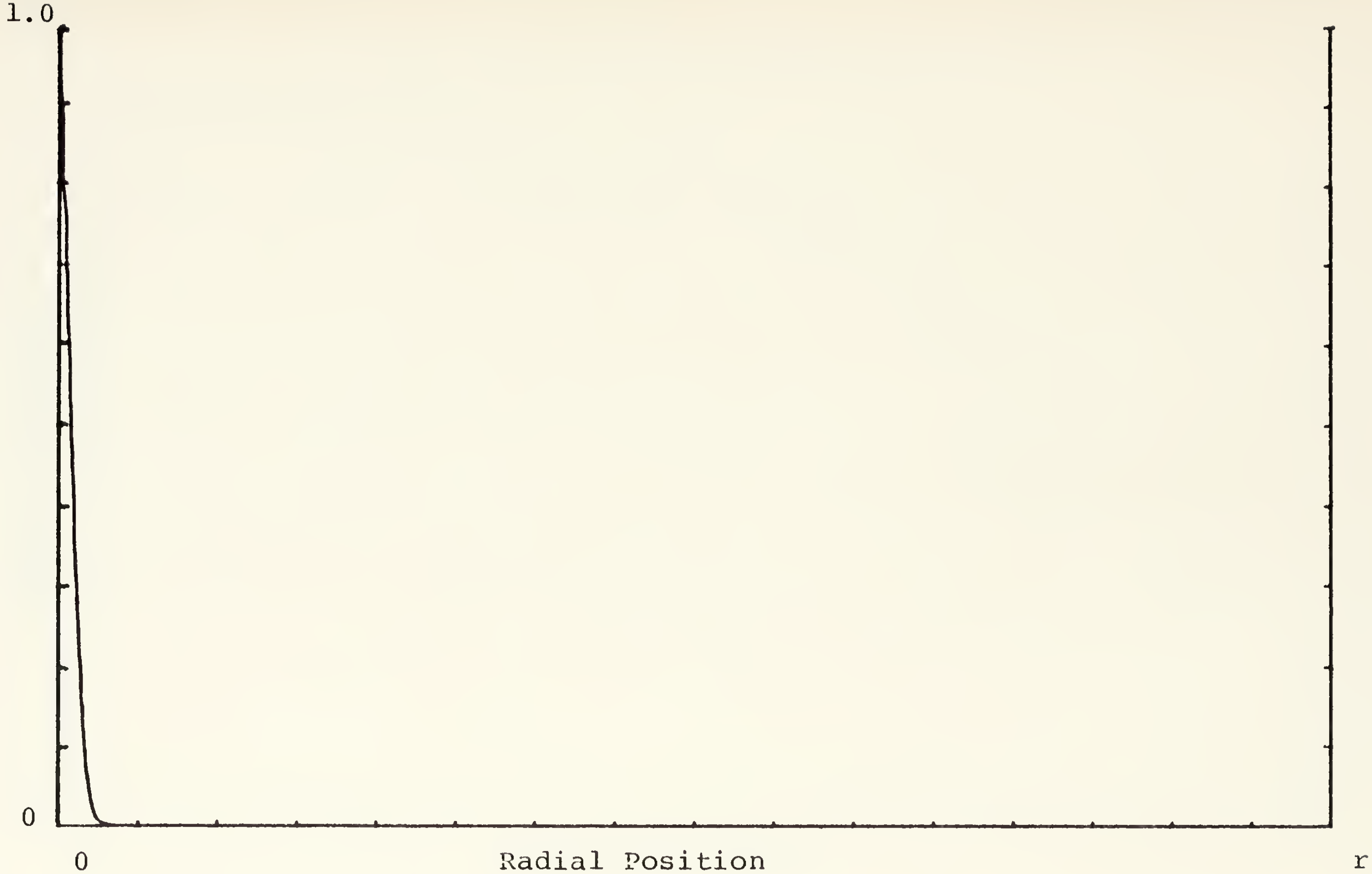

FIGURE 16. "B" INPUT

FIGURE 17. "B" OUTPUT

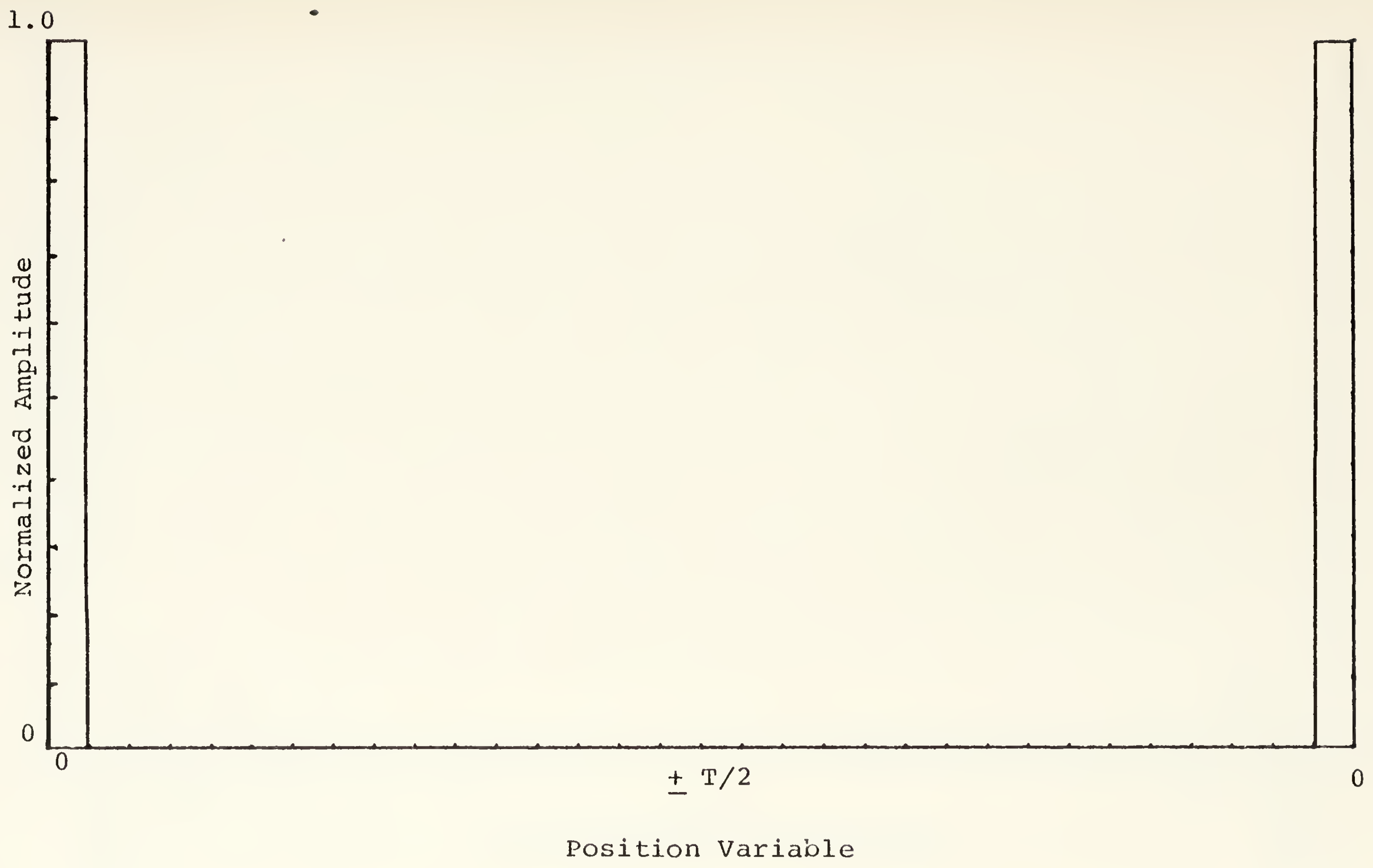

FIGURE 18. FOURIER TRANSFORM INPUT EXAMPLE

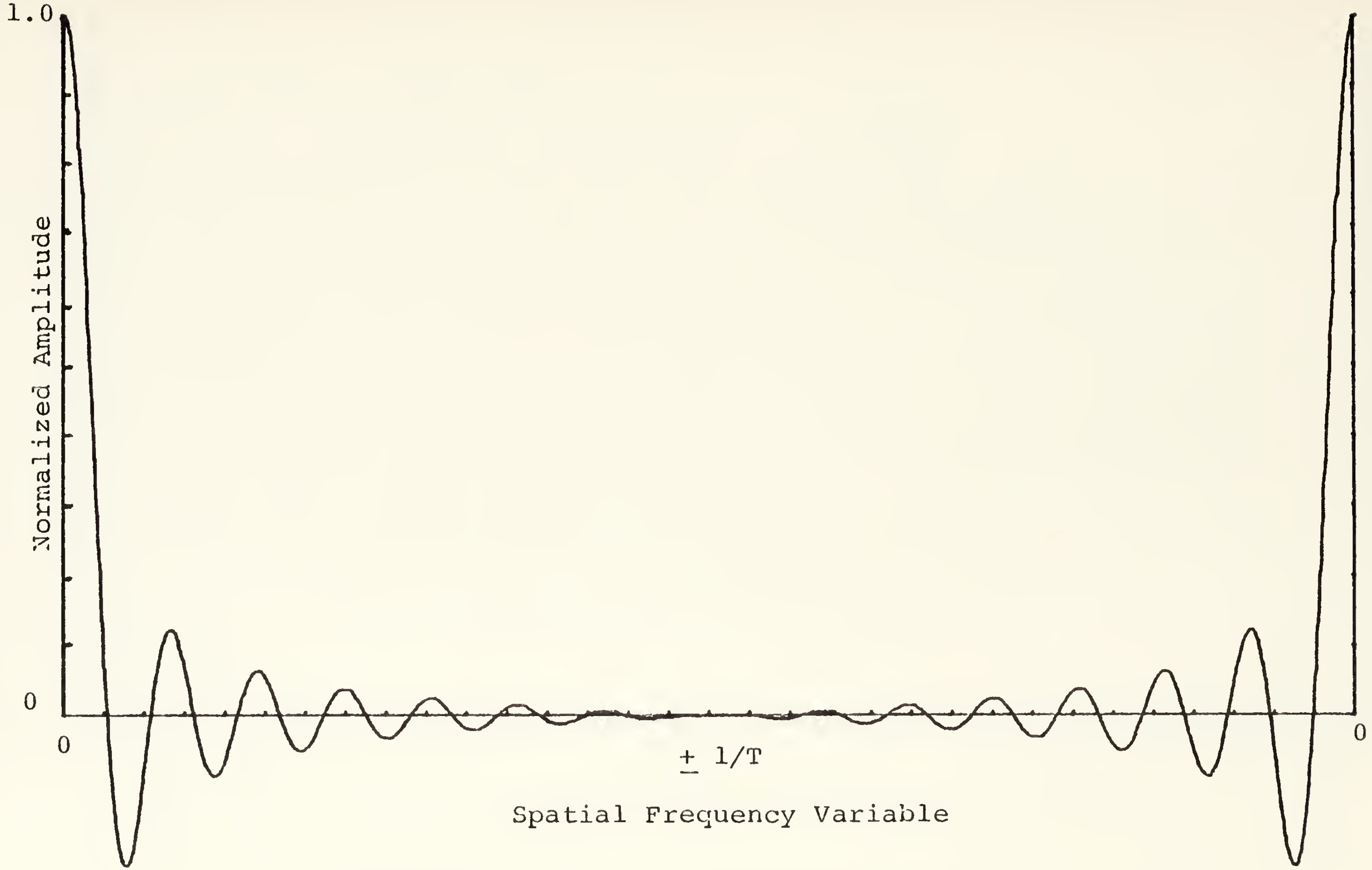

FIGURE 19. FOURIER TRANSFORM OUTPUT EXAMPLE

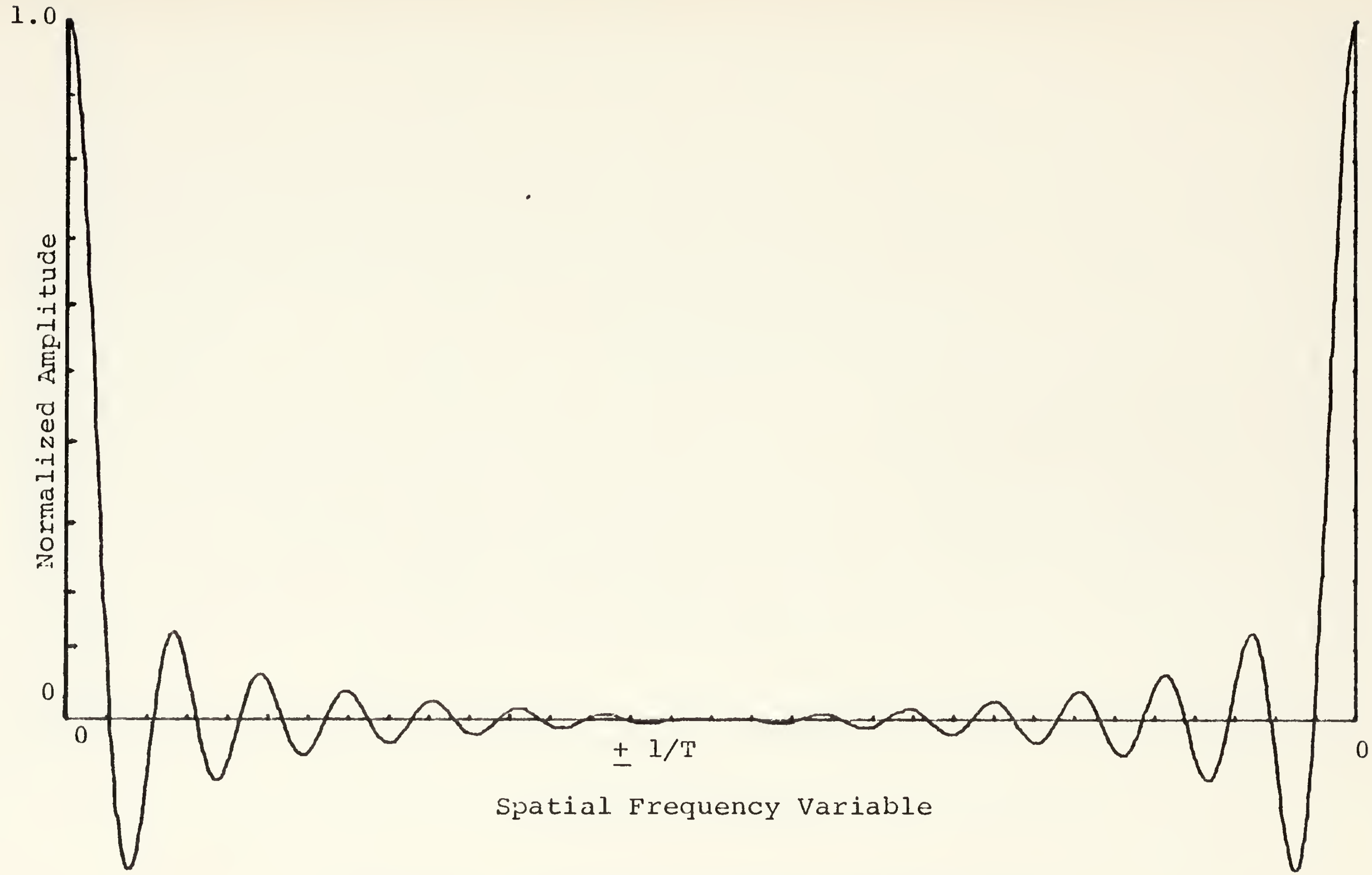

FIGURE 20. INVERSE TRANSFORM INPUT EXAMPLE

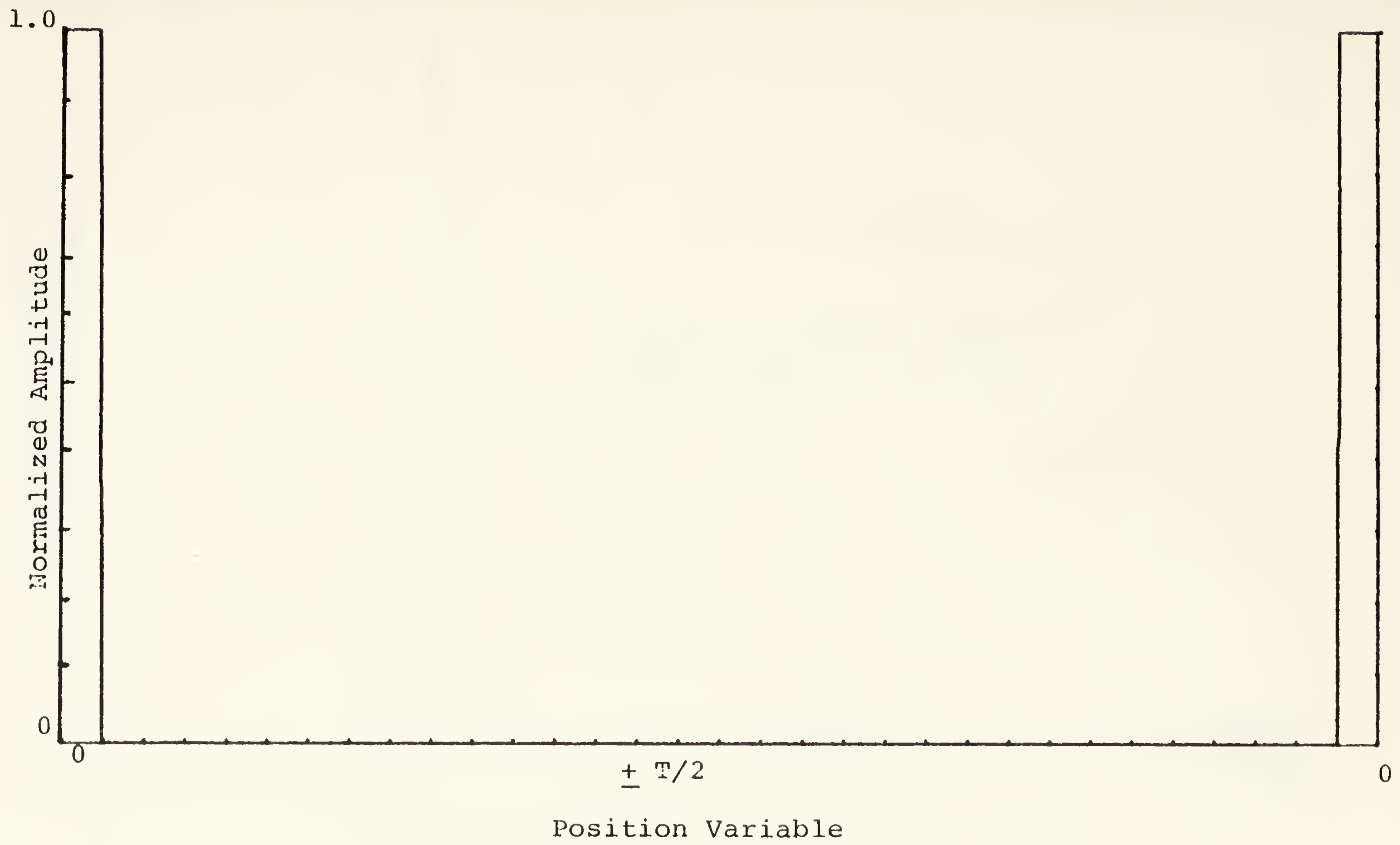

FIGURE 21. INVERSE TRANSFORM OUTPUT EXAMPLE

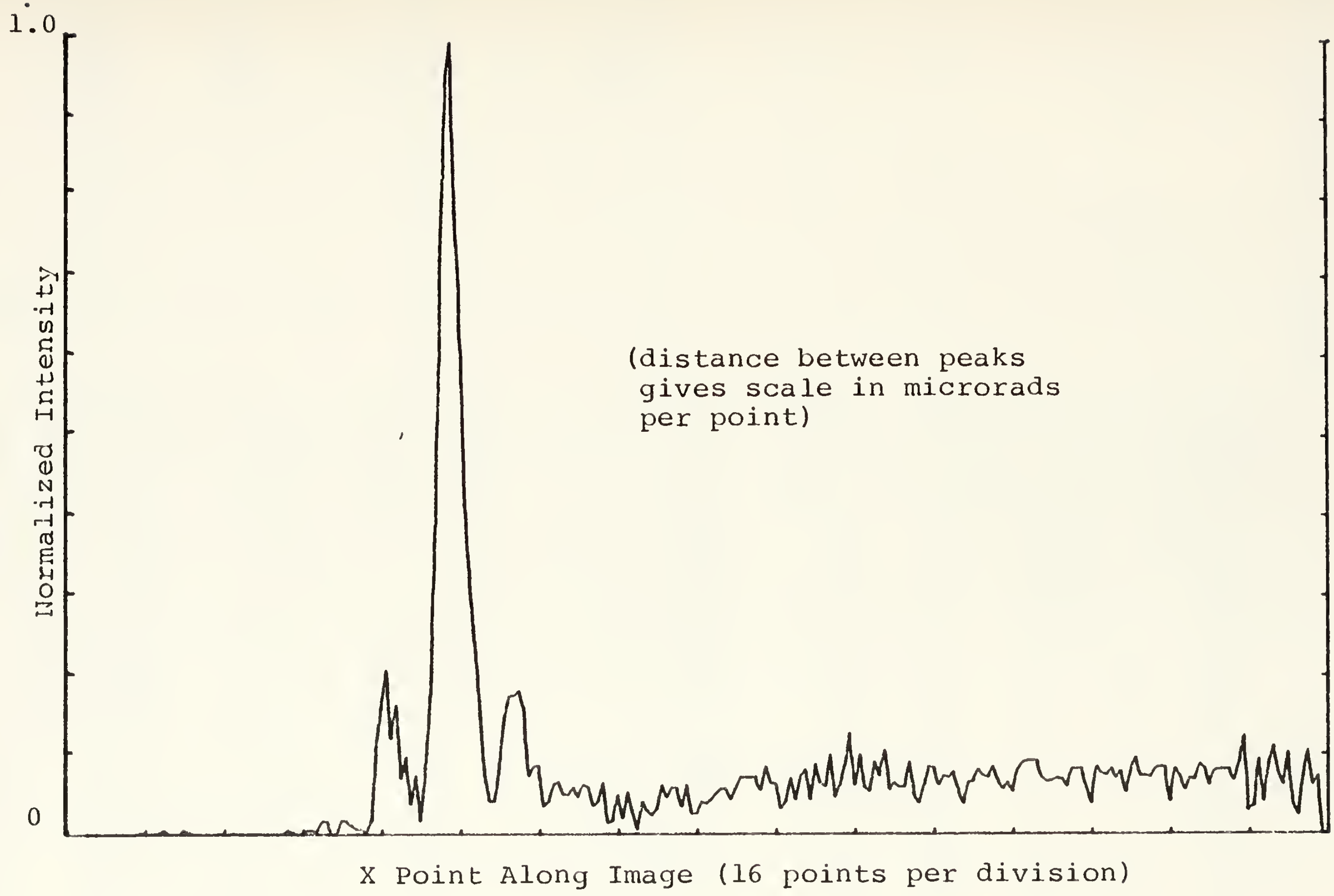

FIGURE 22. SCALE IMAGE EXAMPLE

TABLE 1

INPUT/OUTPUT PARAMETERS

ARRAY VARIABLE	VALUES	USE
O(1)	0	Same as 1 except program after one time through ends, not allowing for computations with new range, C_n^2, ext. coeff.
	1	Source pattern input is point spread function.
	2	Source pattern input is line spread function.
	3	Source pattern input is modulation transfer function of laser only.
	4	Source pattern input is modulation transfer function of source and optics.
	5	Source pattern is to be calculated with amplitude and sigma of intensity distribution as factors.
O(2)	0	Optics diffraction input as PSF.
	1	Optics diffraction input as LSF.
	2	Optics diffraction pattern to be calculated as PSF.
O(3)	0	No plot of source line spread function is required.
	>0	Plots source line spread function (available only if O(1)=0,1 or 5).
O(4)	0	No plot of source MTF required.
	>0	Plots source MTF (available only if O(1) does not equal 3 or 4).
O(5)	0	No plot of product of source and optics MTF required.
	>0	Plots product of source and optics MTF's (available only if O(1) does not equal 4).

TABLE 1 (CONT'D)

ARRAY VARIABLE	VALUE	USE
O(6)	0	No plot of optics diffraction PSF required.
	>0	Plots optics diffraction PSF (available only if O(1) does not equal 4 and O(2)=2).
O(7)	0	No plot of optics LSF required.
	>0	Plots optics LSF (available only if O(1) does not equal 4 and O(2) does not equal 1).
O(8)	0	No plot of optics MTF required.
	>0	Plots optics MTF (available only if O(1) does not equal 4).
O(9)	0	No plot of atmosphere MTF required.
	>0	Plots atmosphere MTF.
O(10)	0	No plot of system MTF.
	>0	Plots total system MTF.
O(11)	0	No plot of LSF of predicted target spot.
	>0	Plots LSF of target spot.
O(12)	0	No plot of target PSF required.
	>0	Plots target PSF.
O(13)	0	No plot of the fraction of power inside circle required.
	>0	Plots fraction of power inside a circle of radius r.
O(14)	0	No plot of calculated source PSF required.
	any other value	Plots calculated source PSF.

TABLE 1 (CONT'D)

ARRAY VARIABLE	VALUES	USE
O(15)	0	Plots measured LSF of target spot.
	>0	Used as indicators of output branching only, entry value not significant.
O(16)	1	Inputs source with diffraction grating from DS-30 for scale computations from output. No output plotted.
	2	Same as 1 except plots the above.
	any other value	Does not do above input

APPENDIX C

PROGRAM LISTING

```
0: dim B$[23],C$[5],D$[7],I$[272],O$[5],P$[5],Q$[5],X$[40],R[
512],I[512]
1: dim O[16],A$[13],Y$[40],Z$[40]
2: files O,T,E,R,G,V,W,C,I,F
3: fmt 1,z,c
4: time 150
5: cfg 3;cfg 2;cfg 1
6: rread 7,1;sprt 7,R[*];rread 7,1
7: buf "DATA",I$,3
8: rread 4,1;sprt 4,R[*]
9: beep
10: "INPUT I/O CONTROL O[I]":
11: for I=1 to 16;ent O[I];next I
12: if O[1]=2;gsb "SOURCE"
13: clr 704
14: if O[16]=1 or O[16]=2;gsb "SCALE"
15: beep;dsp "ENSURE VIDEODISC ON THEN PRESS CONTINUE"
16: stp
17: beep;ent "# OF FRAMES TO AVERAGE",H
18: ent "WINDOW WIDTH ,FIRST PIXEL",r9,"LAST PIXEL",r10
19: H+1→H
20: 0→r3
21: for O=1 to H by 4
22: for I=2 to 9
23: char(47)&char(55)&char(64)&char(80)&char(96)→C$
24: if I=2;"930 020"→D$
25: if I=3;"020"→D$
26: if I=4;"930 120"→D$
27: if I=5;"020"→D$
28: if I=6;"930 220"→D$
29: if I=7;"020"→D$
30: if I=8;"930 320"→D$
31: if I=9;"020"→D$
32: if len(D$)<4;gto 38
33: char(1)&"2"&char(2)&C$&char(15)&D$[5,7]→E$
34: cli 7
35: wait 100
36: wrt 704,B$
37: cli 7
38: char(46)→C$[1,1]
39: char(1)&"2 "&char(2)&C$&char(15)&D$[1,3]→A$
40: cli 7
41: wait 100
42: wrt 704,A$
43: cli 7
44: if I#3 or O>1;gto 47
```

```
45: dsp "BACKGROUND RECORDED"
46: wait 500;dsp "CONTINUE WHEN NXT FRAME READY";stp
47: if D$#"020" or I=3 or I=9 and O<5;gto 49
48: dsp "CONT. WHEN NXT FRAME SELECTED";stp
49: next I
50: if H-O+1<4;gto 53
51: for X=1 to 4
52: gto 54
53: for X=1 to H-O+1
54: "!"&"0"&"A"&"P"&char(96)→P$
55: if X#1;gto 57
56: 1→J;0→Y;gto 62
57: if X#2;gto 59
58: sfg 3;256→J;0→Y;gto 62
59: if X#3;gto 61
60: 1→J;255→Y;gto 62
61: 256→J;255→Y
62: for L=1 to 256
63: dsp L
64: 0→D;""→O$;Y+1→Y
65: Y*512+J→S
66: for I=2 to 6
67: int(S/16)→T
68: T→U
69: S-T*16+I*16→T
70: U→S
71: O$&char(T)→O$
72: next I
73: char(1)&"="&char(34)&char(2)&O$&char(3)&P$&char(15)→B$
74: fmt 1,z,c
75: cli 7
76: wrt 704.1,B$
77: buf "DATA"
78: tfr 704,"DATA",256
79: rds("DATA")→E;if E=-1;jmp 0
80: for I=r9 to r10
81: num(I$[I,I])→Z
82: D+Z→D
83: next I
84: D/(r10-r9)→R[L]
85: next L
86: if flg3=0;gto 91
87: "TAKE DIFFERENCE OF IMAGE AND BACKGROUND":
88: rread 3,1;sread 3,I[*];for I=1 to 256
89: abs(R[I]-I[I])→R[I];next I
90: gto 93
91: rread 3,1;sprt 3,R[*]
92: gto 113
93: 0→G;0→F
94: for I=30 to 226
```

```
95: R[I]+G→G;next I
96: for I=30 to 226;R[I]+F→F
97: if F>=G/2;gto 99
98: next I
99: I→A
100: if O=1 and X=2;1→r1
101: r1-A→r2
102: for J=1 to 256+r2
103: R[J-r2]→R[J]
104: if J<256+r2;next J
105: for K=256+r2 to 256
106: 0→R[K]
107: next K
108: sprt 7,r2
109: rread 4,1;sread 4,I[*]
110: for I=1 to 256
111: I[I]+R[I]→R[I];next I
112: rread 4,1;sprt 4,R[*]
113: next X;next O
114: "TAKE AVERAGE OF ALL FRAMES":
115: for I=1 to 256;R[I]/(H-1)→R[I];R[I]→R[513-I];next I
116: rread 4,1;sprt 4,R[*]
117: if O[15]<1;gsb "OUTPUT"
118: beep
119: ent "RANGE",R,"SQCN",Q,"EXT COEF",E,"WAVLNGTH",W,"OBJ LE
NS",O
120: ent "OBS/OBJ",B,"SCALE",r11;sprt 6,R,Q,E,W,O,B,r11
121: "SYSTEM DATA-W=WAVLNTH IN METERS O=DIA OF OBJ LENS IN ME
TERS":
122: "B=DIA OF OBSUR/DIA OF OBJ LENS r11=SCALE OF DATA IN MIC
RORADS/PT":
123: "R=DISTANCE TO TGT IN METERS":
124: "Q=SQUARE OF ATMOS TURB INDEX IN METERS^-2/3":
125: "E=EXTINCTION COEFF (1/METERS)":
126: if O[1]#5;gto 140
127: beep
128: ent "AMPLITUDE",A,"SIGMA",C
129: for I=1 to 256
130: r11*(I-1)→F
131: F^2/(2*C^2)→G
132: if G>13;gto 134
133: A*exp(-G)→I[I];I→K;gto 135
134: 0→I[I]
135: next I
136: rread 5,1;sprt 5,I[*];rread 5,1;sread 5,R[*]
137: 1→O[15];if O[14]#0;gsb "OUTPUT"
138: gto 149
139: "SOURCE PATTERN DATA INPUT":
140: rread 2,1;sread 2,R[*]
141: for I=1 to 256
142: I→K
```

```
143: if R[I]<-500;gto 146
144: next I
145: gto 149
146: for J=I to 256
147: 0→R[J]
148: next J
149: O[1]→I
150: "BRANCH ACCORDING TO TYPE OF SOURCE PATTERN DATA":
151: gto 152;if I>1;gto 155;if I>2;gto 161;if I>3;gto 206;if
I>4;gto 152
152: "CONVERTS SOURCE POINT SPREAD FUNCTION TO LINE SPREAD FC
N":
153: gsb "LSF"
154: 2→O[15];if O[3]>0;gsb "OUTPUT"
155: "CALCULATION OF FOURIER TRANSFORM OF LINE SPREAD FCN OF
SOURCE":
156: for I=1 to 256
157: R[I]→R[513-I];next I
158: gsb "FXFORM"
159: rread 5,1;sprt 5,R[*]
160: 3→O[15];if O[4]>0;gsb "OUTPUT"
161: if O[2]=2;gto 173
162: "OPTICS DIFFRACTION INPUT IF NOT CALCULATED":
163: rread 8,1;sread 8,R[*]
164: for I=1 to 256
165: I→K
166: if R[I]<-500;gto 169
167: next I
168: gto 182
169: for J=I to 256
170: 0→R[J];next J
171: gto 182
172: "CALCULATION OF DIFFRACTION LIMIT POINT SPREAD FCN":
173: B^2→D;1-D→H;3.14159e-6*r11*O/W→Z
174: for I=1 to 256
175: Z*(I-1)→Y;if Y>30;gto 178
176: (´AIRY´(Y)-D*´AIRY´(Y*B))^2/H^2→R[I]
177: I→K;gto 179
178: 0→R[I]
179: next I
180: rread 8,1;sprt 8,R[*]
181: 4→O[15];if O[6]>0;gsb "OUTPUT"
182: if O[2]=1;gto 188
183: "CONVERTS OPTICS POINT SPREAD FCN TO LINE SPREAD FCN":
184: rread 8,1;sread 8,R[*]
185: gsb "LSF"
186: rread 8,1;sprt 8,R[*]
187: 5→O[15];if O[7]>0;gsb "OUTPUT"
188: "TAKES FOURIER TRANSFORM TO GET OPTICS MODULATION TRANSF
ER FCN":
```

```
189: rread 8,1;sread 8,R[*]
190: for I=1 to 256
191: R[I]→R[513-I];next I
192: gsb "FXFORM"
193: for I=1 to 256
194: if R[1]=0;gto 196
195: R[I]/R[1]→R[I];next I
196: rread 8,1;sprt 8,R[*]
197: 6→O[15];if O[8]>0;gsb "OUTPUT"
198: "CALCULATION OF THE PRODUCT OF TWO FOURIER TRANSFORMS":
199: rread 8,1;sread 8,R[*];rread 5,1;sread 5,I[*]
200: for I=1 to 256
201: R[I]*I[I]→R[I];next I
202: rread 10,1;sprt 10,R[*]
203: 7→O[15];if O[5]>0;gsb "OUTPUT"
204: exp(-E*R)→X
205: "ATMOS MODULATION TRANSFER FCN CALC-SHORT TERM":
206: Q*R*21.6→A;W^(-.3333333)→B;0→V;0→L;X→R[1]
207: for I=2 to 256
208: gto 214;if L<=0;gto 215;if L=0;gto 209
209: 976.5625*(I-1)/r11→T;A*T^1.666667*(B-(T/O)^.3333333)→G
210: sfg 14
211: if G>13;1→L
212: if G-V<0;-1→L
213: G→V;X*exp(-G)→R[I];I→K;cfg 14;gto 218
214: 0→R[I];gto 218
215: R[K]*cos((I-K)*3.14159/K)^2→R[I]
216: gto 217;if I-3*K/2<0;gto 218
217: I→K;1→L
218: next I
219: rread 9,1;sprt 9,R[*]
220: 8→O[15];if O[9]>0;gsb "OUTPUT"
221: "TRANSFER FCN OF SOURCE*OPTICS*ATMOSPHERE":
222: rread 10,1;sread 10,R[*];rread 9,1;sread 9,I[*]
223: for I=1 to 256
224: I[I]*R[I]→I[I]
225: I[I]→R[I]
226: R[I]→R[513-I]
227: next I
228: 9→O[15];if O[10]>0;gsb "OUTPUT"
229: "INVERSE FOURIER TRANSFORM GIVES TARGET LINE SPREAD FCN"
:
230: sfg 1;gsb "FXFORM";I→K;cfg 1
231: 10→O[15];if O[11]>0;gsb "OUTPUT"
232: "CONVERTS LINE SPREAD FCN TO POINT SPREAD FCN BY ABEL TR
ANSFORM":
233: gsb "ABEL"
234: 11→O[15];if O[12]>0;gsb "OUTPUT"
235: "CALCULATES THE FRACTION OF THE POWER INSIDE A CIRCLE OF
 RADIUS R":
```

```
236: gsb "B"
237: 12→O[15];if O[13]>0;gsb "OUTPUT"
238: "READ IN NEW RANGE AND Q IF RANGE NEG. READ IN ALL NEW D
ATA":
239: "STARTING WITH I/O CONTROL CARD,IF RANGE=0 PROGRAM STOPS
":
240: "IF RANGE IS POS. THE PROGRAM CARRIES OUT CALC´S WITH TH
E NEW":
241: "RANGE AND Q":
242: if O[1]=0;gto 245
243: ent "RANGE",R,"SQCN",Q,"EXT COEF",E
244: gto 206;if R<=0;gto 119;if R=0;gto 245
245: end
246: "ABEL":R[1]→N;1.4R[1]-1.8R[2]+.4R[3]→R[1];for I=2 to K
247: R[I]→M
248: .4N+.2M-.6R[I+1]→R[I];M→N;next I
249: for I=1 to K
250: R[I]/(2*√((I+.1)^2-II))→R[I]
251: for J=I+1 to K
252: R[I]+R[J]/√((J+.1)^2-II)→R[I]
253: next J;R[I]/π→R[I];dsp I;next I
254: ret
255: "LSF":for I=1 to K
256: 1→J;dsp I;R[I]→Z
257: √(I*I+J*J)→Y
258: 2*((1-frc(Y))*R[int(Y)]+frc(Y)*R[int(Y)+1])+Z→Z
259: J+1→J;if Y<K;jmp -2
260: Z→R[I];next I;ret
261: "B":.25πR[1]→R[1]
262: for I=2 to K
263: 2πIR[I]+R[I-1]→R[I]
264: next I
265: if R[K]=0;ret
266: for I=1 to K;R[I]/R[K]→R[I];next I;ret
267: "AIRY":if p1<0;beep;dsp "ERROR p1<0";stp
268: if p1=0;1→r4;ret r4
269: 0→r5;if p1>15;jmp 2
270: 20+10p1-p1^(2/3)→r6;jmp 2
271: 90+p1/2→r6
272: if p1<5;6+p1→r12;jmp 2
273: 1.4*p1+60/p1→r12
274: max(int(r12),int(3+p1/4))→r12
275: for M=r12 to r6 by 3;1e-28→r8;0→r13→r14
276: sfg 10;if M/2=int(M/2);cfg 10
277: for J=1 to M-2;2*(M-J)*r8/p1-r13→r15;r8→r13
278: r15→r8;if M-J-2=0;r15→r4
279: cmf 10;r14+2*r8*flg10→r14;next J
280: 2*r8/p1-r13→r15
281: r14+r15→r14;r4/r14→r4
282: if abs(r4-r5)-abs(r4*1e-6)<=0;2*r4/p1→r4;ret r4
283: r4→r5;next M
```

```
284: beep;dsp "Accuracy not obtained";wait 1000;ret r4
285: "FXFORM":rad;9→N;ina I
286: π/2^(N-1)→T
287: for M=1 to N;2^(N-M)→r16
288: for J=0 to 2^(M-1)-1;cll 'BI'(J,P,N-1)
289: cos(PT)→C;sin(PT)(1-2flg1)→P
290: for I=2r16J+1 to 2r16J+r16
291: R[I]→r0;R[I+r16]→r1
292: I[I]→r2;I[I+r16]→r3
293: r0+r1*C+r3*P→R[I];r2+r3*C-r1*P→I[I]
294: r0-r1*C-r3*P→R[I+r16]
295: r2-r3*C+r1*P→I[I+r16]
296: next I;next J;next M
297: for I=0 to 2^N-1;cll 'BI'(I,J,N);if I-J>0;jmp 8
298: if I=J;jmp 5
299: R[I+1]/√(2^N)→P
300: I[I+1]/√(2^N)→Z
301: R[J+1]→R[I+1];I[J+1]→I[I+1]
302: P→R[J+1];Z→I[J+1]
303: R[I+1]/√(2^N)→R[I+1]
304: I[I+1]/√(2^N)→I[I+1]
305: next I;deg;ret
306: "BI":0→p2;p1→p4
307: for Z=1 to p3
308: p4/2→p4;2p2→p2
309: if frc(p4)#0;p2+1→p2
310: int(p4)→p4;next Z;ret
311: "SOURCE":sfg 2
312: beep;dsp "DISPLAY SOURCE IMAGE ON VID DISC";wait 3000
313: cll 'SCALE'
314: rread 2,1;sprt 2,R[*]
315: cfg 2;ret
316: "SCALE":if flg2;gto 318
317: beep;dsp "DISPLAY SCALE IMAGE ON VID DISC";wait 3000
318: dsp "THEN PRESS CONTINUE";stp
319: ent "WINDOW WIDTH, FIRST PIXEL",r9,"LAST PIXEL",r10
320: for I=2 to 3
321: char(47)&char(55)&char(64)&char(80)&char(96)→C$
322: if I=2;"930 020"→D$
323: if I=3;"020"→D$
324: if len(D$)<4;jmp 5
325: char(1)&" 2"&char(2)&C$&char(15)&D$[5,7]→B$
326: cli 7
327: wait 100
328: wrt 704,B$
329: char(46)→C$[1,1]
330: char(1)&"2 "&char(2)&C$&char(15)&D$[1,3]→A$
331: cli 7
332: wait 100
333: wrt 704,A$
```

```
334: next I
335: "!"&"0"&"A"&"P"&char(96)→P$
336: 1→J;0→Y
337: for L=1 to 256
338: dsp L
339: 0→D;""→O$;Y+1→Y
340: Y*512+J→S
341: for I=2 to 6
342: int(S/16)→T;T→U;S-T*16+I*16→T
343: U→S;O$&char(T)→O$
344: next I
345: char(L)&"="&char(34)&char(2)&O$&char(3)&P$&char(15)→B$
346: cli 7
347: wrt 704.1,B$
348: buf "DATA"
349: tfr 704,"DATA",256
350: rds("DATA")→E;if E=-1;jmp 0
351: for I=r9 to r10
352: num(I$[I,I])→Z;D+Z→D
353: next I
354: D/(r10-r9)→R[L]
355: next L
356: if flg2;gto 358
357: if O[16]=2;gsb "OUTPUT"
358: ret
359: "OUTPUT":
360: beep
361: dsp "STOP IF PLOTTER NOT READY THEN CONTINUE";wait 5000
362: sfg 14;'MIN'(256)/'MAX'(256)→r17;cfg 14
363: if r17<-.1;scl -.75,1.05,-30,264;plt 1,0,1;jmp 2
364: scl -.15,1.05,-30,264;plt 1,0,1
365: for I=10 to 0 by -1
366: plt I/10,0,2;plt I/10,256/150,2
367: plt I/10,0,2;next I
368: for I=0 to 16
369: plt 0,16I,2;plt 1/150,16I,2
370: plt 0,16I,2
371: next I
372: pen;csiz .9,1,1.4
373: fxd 0;for I=16 to 0 by -1;plt -.1,16I-1,1
374: lbl 16(16-I);next I
375: fxd 1;for I=0 to 10;plt I/10-.06,-5,1
376: lbl I/10;next I
377: if O[15]=10 or O[15]=0;"TARGET LINE NUMBER"→Y$
378: if O[15]=1 or O[15]=11;"POSITION VALUE"→Y$
379: if O[15]=10;"PREDICTED NORMALIZED LINE VALUE"→X$
380: if O[15]=0;"MEASURED NORMALIZED LINE VALUE"→X$
381: plt -.12,51,1;csiz 1.2,1,1.4,90;lbl Y$
382: plt 0,-13,1;csiz 1.2,1,1.4;lbl X$
383: csiz .5,1,.7,0
```

```
384: 'MAX'(256)→r7
385: if r7=0;1→r7
386: for J=1 to 256
387: plt R[J]/r7,257-J;next J
388: pen;ret
389: "MIN":R[1]→p2
390: for I=2 to p1;if R[I]>p2;jmp 2
391: R[I]→p2
392: next I;ret p2
393: "MAX":R[1]→p2
394: for I=2 to p1;if R[I]<p2;jmp 2
395: R[I]→p2
396: next I;ret p2
*21194
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LIST OF REFERENCES

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